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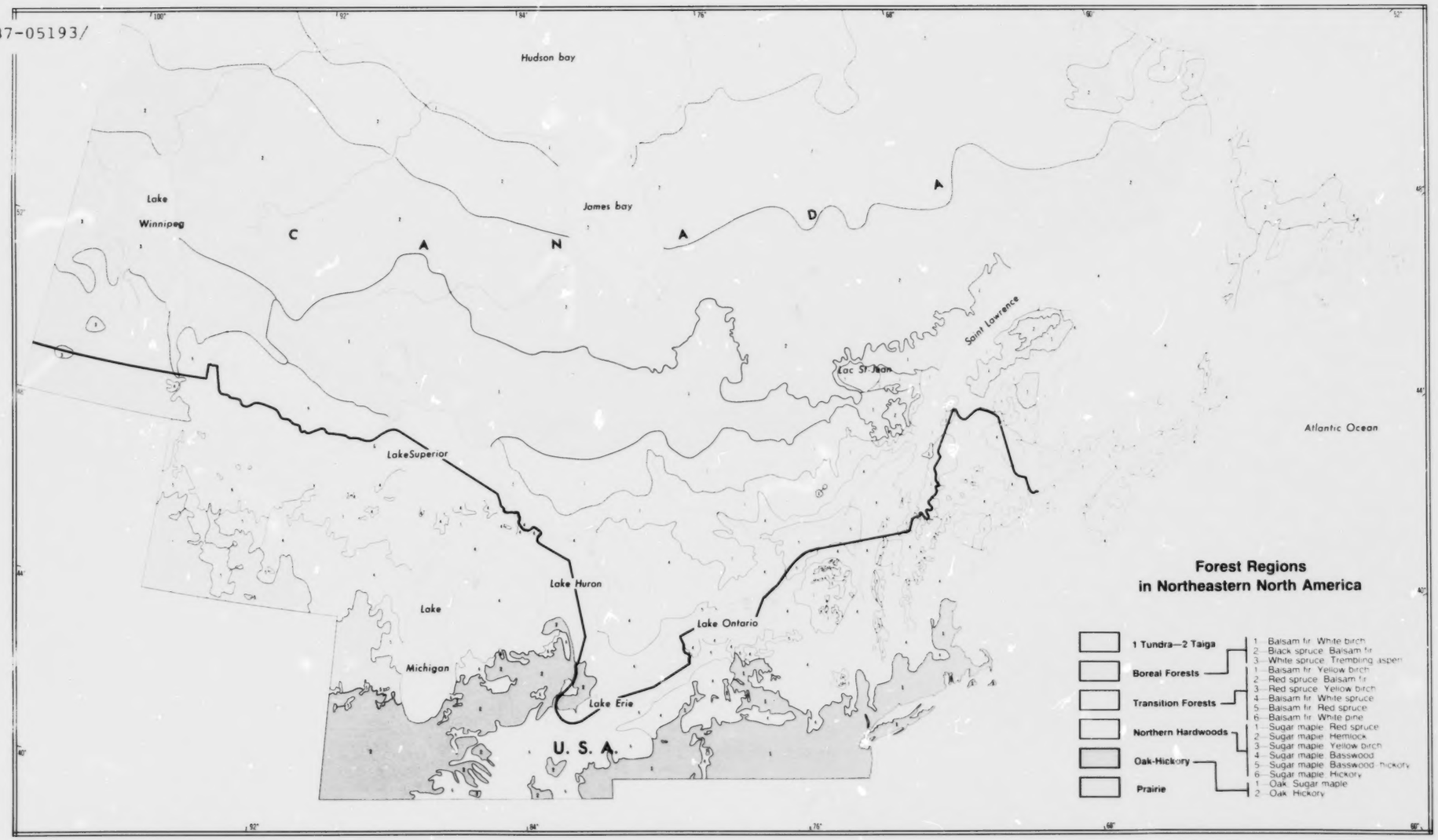
Hudson bay
James bay
Lake Winnipeg
CANADA
Saint Lawrence
Lac St-Jean
Atlantic Ocean
LakeSuperior
Lake Huron
Lake Michigan
Lake Ontario
Lake Erie
U. S. A.
Forest Regions in Northeastern North America
1 Tundra—2 Taiga
Boreal Forests
1—Balsam fir. White birch
2—Black spruce. Balsam fir
3—White spruce. Trembling aspen
Transition Forests
1—Balsam fir. Yellow birch
2—Red spruce. Balsam fir
3—Red spruce. Yellow birch
4—Balsam fir. White spruce
5—Balsam fir. Red spruce
6—Balsam fir. White pine
Northern Hardwoods
1—Sugar maple. Red spruce
2—Sugar maple. Hemlock
3—Sugar maple. Yellow birch
4—Sugar maple. Basswood
5—Sugar maple. Basswood. hickory
6—Sugar maple. Hickory
Oak-Hickory
1—Oak. Sugar maple
2—Oak. Hickory
Prairie

An Atlas of Spruce Budworm Defoliation in Eastern North America, 1938–80

by

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Cover: *Spruce budworm killed the spruce and fir in this mixed stand of sawtimber-size trees in Kabonga, Québec. The photograph was taken by the USDA Forest Service in August of 1949. (#704585 in the collection of the National Agricultural Library, Beltsville, MD)*

Introduction

The spruce budworm, *Choristoneura fumiferana* (Clemens), is indigenous to eastern North America, where its principal hosts are balsam fir (*Abies balsamea* [L.] Mill) and the spruces, white, red, and black (*Picea glauca* [Moench] Voss, *P. rubens* Sarg., and *P. mariana* [Mill.] B.S.P.). Because spruce and fir are indicator species for the boreal forest in North America, entomologists customarily associate budworm with it; and, indeed, outbreaks in colonial times (Blais 1960) seem to have been restricted to the true boreal forest.

Until the start of the 20th century, budworm seems to have been a rather innocuous forest insect. Outbreaks occurred sporadically and did not persist. Its changed status, however, has been noted by Blais (1983), Tothill (1922), Swaine (1922), and Bailey (1924), among others. At present it is the most devasting forest insect in North America, whether measured by hectares infested, numbers and volume of trees killed, or frequency and duration of outbreaks.

Although scientists contributed substantially to our knowledge of budworm biology coincident with efforts to control it, budworm epidemiology remains speculative. The increased frequency and duration of outbreaks in modern times suggest, in addition to some irregular climatic "trigger," that an environmental change of substantial scale favoring the buildup and spread of budworm populations occurred during the present century.

Previous publications impressively document the character of budworm outbreaks through time by means of small-scale maps showing the location and magnitude of outbreaks annually from 1909 to 1966 (Brown 1970) and from 1967 to 1980 (Kettela 1983). But the compression of information to accommodate the map scale gives few clues to the development of outbreaks and makes it impossible to associate the chronologic infestation dynamics with the supporting vegetation. It is in the linkage between the budworm and the budworm forest, and the recognition that both are capable of change but on different time scales (Holling et al. 1976), that we must look to for an understanding of budworm dynamics.

The senior author's longstanding interest in budworm dynamics led him to assemble, with the assistance of cooperators and students, budworm defoliation information from 1938 to 1980 for the region from Manitoba to Newfoundland and including the States of Maine and Minnesota. By the late 1930's, industrial foresters and natural resource agencies, recognizing the value of the resource being wasted by budworm, commenced aerial reconnaissance of budworm-affected areas within their jurisdictions and mapped defoliation, thus greatly improving the resolution and quality of infestation information. In addition, the senior author and his students conducted vegetation analyses of locales in Québec, Ontario, New Brunswick, Manitoba, and Maine for which the evolution and spread of an outbreak were well documented. Finally, because most entomologists believe that a climatic trigger is the proximate cause of budworm population surges, he assembled available long-term climatic data for the principal budworm regions. The climatic trigger, if a unique one exists, still eludes scientists; but from the data he constructed zones of budworm abundance that enhance interpretation of budworm population and vegetation information.

This atlas shows defoliation on annual maps, like its predecessors, but at a much larger scale (approx. 1:11 million *vs.* approx. 1:40 million). It consists of a vegetation map for the budworm region in eastern North America (plate I), a grid map showing the frequency of outbreaks from 1954 to 1980 by grid square (plate II), and a defoliation map for each year from 1938 to 1980 (plates III–XLV). Each plate also features a corridor running east–west across the budworm region, whose northern and southern boundaries are isotherms. The significance of the corridor can be appreciated by consulting its location on the vegetation (zone B) and grid maps.

The research that supports the presentation of this atlas was undertaken to gain a better understanding of spruce budworm dynamics, and we believe the atlas will provide students of budworm epidemiology with a unique and provocative source of information, although we anticipate that some scientists will offer different interpretations from ours. Professional foresters and landowners who must cope with the budworm problem will find the grid map, with its cumulative frequency of outbreaks by grid square, immediately useful because the cumulative frequency is a crude measure of the degree to which the lands within a grid square are at risk from budworm.

Preparation of the Maps

Forest Vegetation Map

Because budworm epidemiology can be understood only in relation to its associated vegetation, we constructed a map for the budworm region of eastern North America showing the location of the major forest associations in and near the region of concern. We consulted several excellent national and regional vegetation maps based on ecological principles for this purpose (Bailey 1978, Küchler 1964, Rowe 1972). However, the nomenclature of the associations differs depending on the purpose of the author; and the location of type boundaries, always a difficult task, is exacerbated when source material is mapped to national and regional boundaries and to different scales. We accomplished a useful integration by carefully scaled transfers of association boundaries that were consistently recognized by the source authorities.

Where nomenclature differences caused location problems, we consulted regional sources such as Grandtner (1966) in Québec, Hill (1958 and 1961) in Ontario, and Loucks (1960) for the Maritime Provinces. In particularly troublesome situations (and there were a few), the on-the-ground experience of the senior author and his students resolved the problem. The nomenclature of the major forest associations (color coded) is the one commonly employed by North American plant ecologists except for Transition Forests. Although plant ecologists recognize that rather broad ecotones exist between major associations, ecotones are rarely mapped because they are vegetative continuums with, in the absence of detailed investigations, imprecise boundaries. In the context of budworm, however, the approximate location of the Transition Forest is of particular significance. Careful review of regional sources and field experience provided sufficient information to locate the boundaries of the Transition Forest approximately and to delineate the subassociations (numerical code, plate I). The nomenclature of the subassociations is based on principal species. The regional sources provided invaluable information for this purpose, but occasionally the same subassociation (as shown by a detailed comparison of species lists, including the understory when available) differed in the designation of principal species (usually just one). In such cases we used the key species of Grandtner (1966) if the subassociation was represented in Québec; if not, we used the regional source description where it is best represented on an areal basis. It is important to bear in mind, however, that the associations mapped, in keeping with Küchler (1964) and Bailey (1978), represent the vegetation potential.

Grid Outline of the Spruce Budworm Region, Eastern North America

Plate II is an outline map of the budworm region, gridded every 1 cm^2 (0.16 in^2) so that each square represents approximately 12,100 km^2 (4,672 mi^2). Squares with numbers are those for which outbreaks were recorded. The number represents the number of times an outbreak occurred in the area between 1954 and 1980 (i.e., cumulative frequency). Boldface numbers indicate frequencies exceeding 5/26. Frequency was determined by placing an acetate map, gridded and to the same scale as plate II, over each annual defoliation map and summing the number of times outbreak conditions occurred within a square.

If 25 percent or more of the forested area within a square registered as defoliated, we recorded it as an outbreak event. Obviously "outbreak" is a term of convenience, but the 25 percent rule excludes presence on a relatively small area and captures spread, both concepts essential to the notion of "outbreak."

In a very few cases defoliation occurred for a number of consecutive years but never exceeded 25 percent of the forested area within the square. Since the vegetation associations and subassociations represent potential budworm vegetation, these cases may indicate the presence of substantial areas of forest in which host species are lacking. Based on our knowledge of the forest in the areas within such squares, and the pattern as it developed in adjacent ones, we recorded as a single event defoliation for 4 consecutive years that never exceeded 25 percent of the forest area in the square.

In addition to cumulative frequency by grid square, the map depicts four zones, which refer to the concept of bioclimatic zonation stated by Cook (1929), Huffaker et al. (1976), and Knight and Heikkenen (1980). This concept was applied to the dynamics of spruce budworm outbreaks in Québec by Hardy et al. (1983). Cook's bioclimatic zonation concept implies that the most favorable portion of an insect's range is also the most biologically resilient. Scarcity of host species and predatory activity are the major biological factors involved in keeping a state of equilibrium. In the outer zones, host species might become more abundant, but less favorable climatic conditions usually preserve the equilibrium unless the area is temporarily subjected to better-than-average climatic conditions. In this case, an outbreak becomes possible.

Each zone is an east–west transect across the mapped region. Zones A, C, and D basically correspond to forest vegetation associations. Zone A is principally deciduous forest in which budworm host species are sparsely represented adjacent to the border of zone B. In these conditions, budworm populations are restricted to pockets of host species in which significant defoliation is a rare event. To the south, host species drop out except for high elevation disjuncts (red spruce) in the Appalachians. Except for the precise location of the A–B boundary, zone A can contribute little to an analysis of budworm dynamics. Zones C and D are essentially the major subdivisions of the Boreal Forest, spruce–fir and black spruce, respectively. These zones contain large expanses of host forest and are capable of supporting budworm populations (zone C especially) except at the northern limit of zone D, where subarctic temperatures prevent their establishment.

However, because we wanted to identify more precisely the limits of the zone that offers the most favorable physical conditions, we established the boundaries of zone B on the basis of budworm–temperature relationships. For this purpose, we used the mean annual temperatures of the epicenters reported by Gagnon and Hardy (1983) for the current outbreak and the methodology developed by Bergevin (1985) to account for regional climatic particularities. In this context, an epicenter is considered to be a discrete area of moderate to severe defoliation recorded outside the main body of the infestation and the first indication of defoliation in a given region.

We felt that isotherms corresponding to the mean annual temperatures of the coldest (Chapleau, ON) and warmest (Ashton, ON) epicenters could logically represent the limits of zone B. Therefore, we initially set the boundaries of zone B to correspond to the 1.2 °C (34 °F) and 5.3 °C (41.5 °F) mean annual isotherms. Since the western part of the zone experiences extreme continental conditions, the northern boundary of zone B was modified in the west to exclude areas where the annual mean January temperature is below −18 °C (0 °F) (Ives 1974); and the southern boundary was adjusted to exclude areas in which the sum of the mean monthly temperatures for April, May, June, July, and August exceeded that for Ashton, ON, 72.5 °C (162.5 °F). Ashton is the warmest western epicenter for these critical months. In the east, by contrast, there are areas that warm very slowly compared to the rest of the zone. These areas were excluded by adjusting the northern isotherm in the east to exclude areas whose cumulative mean monthly temperatures for April, May, June, July, and August were less than 54.9 °C (131 °F), the mean sum for St. Elzéar, PQ, the coldest eastern epicenter.

We do not pretend that zone B boundaries are optimally located. However, the development rate of budworm is temperature-sensitive (Miller et al. 1971); and, on the average, populations will reflect climatic variations within a zone. Unfortunately, neither the quality of climatic data, especially for local areas, nor our understanding of the relation of climatic variation to host species quality and budworm population dynamics is good enough to explain why in some situations budworm populations behave as they do. Nevertheless, by delimiting zone B in terms of the warmest and coldest epicenters, a useful—if approximate—"corridor," zone B, which we believe includes most of the outbreak-prone area, was constructed. But further refinement of the boundaries is desirable. For example, zone B is probably too wide, including part of what should be zone A.

Spruce Budworm Defoliation Maps

Plates III to XLV are annual defoliation maps for the period 1938–80. They were compiled from defoliation reports prepared by forest or natural resource agencies in eastern Canada and the United States. In the laboratory we mapped defoliation at a scale of 1:6,336,000. Naturally the reports are not as complete as we would like them; but the detection capabilities of the responsible agencies improved over time, technically and in terms of staff and financial resources.

We did not obtain reports from New Hampshire, Vermont, Wisconsin, or Michigan; but we do not feel that their absence seriously detracts from the interpretation of the information we assembled. The northeastern New Hampshire and Vermont infestations during the current outbreak occurred in extensions of the Maine forest into these States. Likewise, the similarity of the Lake States forests and their cutting history suggest that Minnesota provides an adequate representation of the budworm region for the Lake States.

Although forest entomologists normally report defoliation as light, moderate, or severe, and these distinctions are useful for planning pest-management activities, a level of defoliation that can be detected by reconnaissance procedures is a clear indication of a significant budworm population. Consequently we consistently mapped total defoliation.

The defoliation record for all the mapped areas is complete from 1954 to 1980, but we mapped defoliation from every Province and State for which we had a report between 1938 and 1980, as shown below.

Province/State	*Years*
Manitoba	1938–80
Ontario	1938–80
Québec	1938–80
New Brunswick	1941; 1945–80
Nova Scotia	1950–80
Prince Edward Island	1953–80
Newfoundland	1942–80
Maine	1945–80
Minnesota	1954–80

Since the defoliation record is complete from 1954 to 1980, each map for this period includes a tabular insert showing hectares infested by zone, compiled from the large-scale maps (1:6,336,000). This information is summarized in Plate II. The estimates of defoliation, especially for the period 1970-80 in Québec, New Brunswick, and Maine, may be slightly conservative because the protection programs in these jurisdictions provided excellent foliage protection in some years. This consideration is offset somewhat by bearing in mind that we mapped every class of reported defoliation, including light, which is generally not reported.

Discussion

Some of the analyses and interpretations resulting from the research that led to the production of the atlas have been published elsewhere (Hardy et al. 1983) or will be. Our purpose here is to summarize briefly some of the major characteristics of the current outbreak that are disclosed by careful consideration of the vegetation, grid, and defoliation maps. Before doing so, we should look at the concept of epicenters.

In the early and mid-1970's, many forest entomologists believed that the budworm outbreak cycle was closely linked to balsam fir rotation age, about 40 to 60 years. Outbreaks decimated the fir populations, and the pandemic collapsed. During outbreak intervals, budworm essentially disappeared. If epicenters had not existed, it would have been necessary to invent them. In fact there was fairly persuasive evidence at the time that one or more epicenters, meaning persistent localized populations, existed in central Ontario and eastern Manitoba. Completely convincing documentation of the subsequent propagation of outbreaks from these centers was lacking, however, primarily because at the time the Provinces and States usually did not provide aerial reconnaissance unless there were ground reports of moderate to severe defoliation in several locations. But between 1968 and 1976 Hardy learned that Québec had mapped seven widely separated infestations in the Province, and subsequent annual surveys revealed the propagation of a major outbreak from them which merged in some parts of the Province. When he investigated the vegetation of these incipient infestation areas, he found that it differed in some important ways from the prevailing concepts of budworm/host requirements for epicenters (Hardy et al. 1983). Nineteen additional epicenters, with similar characteristics, were then located. They range from Maine to Manitoba.

The conceptual difficulty with the Québec epicenters and those subsequently identified was that they were located south of the Boreal Forest, i.e., in nonhost type. But vegetative analyses of these epicenters disclosed that budworm host species, though not dominating the regional forest canopy, locally dominated ecologically disturbed areas and tended to be well represented as subcanopy species everywhere in the "epicenter" areas. Clearly the prevailing epicenter concept for budworm had to be enlarged in the sense that if host species were present, the probable occurrence of budworm populations was restricted only by the climate tolerance of the insect. This viewpoint is supported by recent pheromone trapping experience over a wide range of forest cover types in which host species are present.

Moreover, the available cartographic information on budworm infestations, especially this atlas, suggests that budworm epidemics are not episodic and do not consistently start in well-defined locations in the western part of the budworm region. To the contrary, since 1938 major outbreaks have been recorded somewhere in the region almost every year; and quiescent periods, like 1963, are the exception rather than the rule.

Since the experience of forest and forest-pest managers with modern outbreaks, especially in the past two decades, and the results of plant and insect ecology research in the epicenters and elsewhere suggest that the origin, spread, and intensity of budworm outbreaks are in some way different from those expected, we looked for a pattern in the defoliation history mapped in the atlas.

Plate II graphically shows the progress of budworm infestations from 1954 to 1980. It is very clear that the infested area in zone B is consistently higher than in other zones, and that as the outbreak intensified there was a dramatic and disproportionate increase in infested area in zone B. Indeed, a simple interpretation of the increases in zones C and D at this time is that they reflect increased population pressures from zone B. Plate II further shows that almost all the grid squares in which extensive defoliation was reported year after year are located in or adjacent to zone B.

It is obvious that budworm population dynamics and zone B are somehow related; and according to recent research (Blais 1983), they probably have been since the turn of the century. What is peculiar about zone B? Answering this question should be the focus of modern budworm research. But we can identify one pervasive characteristic that reflects the results of a substantially altered environment throughout the zone and suggests that the modifications brought to the forest cover have created a new state of equilibrium where the budworm's host species and physical requirements are present in the same area.

Recalling that zone B boundaries are simply expressions of the climatic regimes in the coldest and warmest epicenters, and referring to plate I, one finds that the northern boundary of zone B corresponds in most places quite closely to the southern boundary of the Boreal Forest. Zone B also includes almost all the Transition Forest. It is not particularly surprising to find in temperate climates an apparent correspondence between isotherms and vegetation boundaries. Clinal variation corresponding to latitudinal temperature regimes is well documented in forest genetics and plant geography literature. But what this says about zone B is that it is almost wholly composed of Transition Forest and northern hardwood species in which yellow birch (*Betula alleghaniensis* Britton) is a key component. In addition, however crudely the selected isotherms define zone B, on the average its climatic regime is more favorable to budworm than those of zones A, C, or D, which include the budworm's climatic tolerance limits. And, as we previously pointed out, host species are abundantly present, though not as vast expanses forming a continuous association.

One conclusion is inescapable: if we are to manage and live with the budworm, it is in zone B, which almost everywhere includes the international boundary between the United States and Canada, where the effort must be made.

Sources of Information on Spruce Budworm Defoliation

In constructing the vegetation and defoliation maps, we relied upon (1) widely available material, which is listed here using the Harvard citation method and fully referenced in the Literature Cited section; and (2) unpublished information not generally available, the titles of which are paraphrased here. The purpose of this source list is to help readers isolate data pertinent to the budworm defoliation history of a particular State or Province.

Maine: Weed 1977; Final Environmental Impact Statement, proposed cooperative spruce budworm suppression project, Maine, 1980; and Kettela 1983.

Maine, Maritimes, and Québec: Webb et al. 1961, Kettela 1983, and Trial 1980. For 1938 to 1950, Forest Insect and Disease Survey in Canada (now known as the Forest Insect and Disease Conditions), Canadian Forestry Service, was used to complete the information on all Provinces.

Minnesota: Erickson and Hastings 1978; and (for 1978 to 1980) Michael Carroll, Minnesota Department of Natural Resources (personal communication).

Newfoundland: Forest Insect and Disease Survey and predecessor titles (1938–80), Brown 1970 (for 1945–64), Otvos and Moody 1978 (for 1942–77), Moody 1980 (for 1978–79), and Hudak and Raske 1981.

Nova Scotia: Forest Insect and Disease Survey (1950–80) and annual forest pest control forum, Ottawa (1972–80).

Prince Edward Island: Forest Insect and Disease Survey (1953–80), annual forest pest control forum (1972–80), and Brown 1970 (for 1961–62).

Québec: The original defoliation maps compiled by the Service d'entomologie et de pathologie, Ministère de l'énergie et des ressources, from 1968 to 1980 were made available by Louis Dorais. Other sources of information were Forest Insect and Disease Surveys and predecessor titles (1938–80) and Brown 1970 (for 1955–67).

Ontario: Forest Insect and Disease Surveys and predecessor titles (1938–80) and Brown 1970 (for 1963–65). Spruce Budworm Situation in Ontario 1970–80, made available by Gordon Howse. For the period 1943–55, Eliott 1960.

Manitoba: Forest Insect and Disease Surveys and predecessor titles (1938–80) and Hildahl and DeBoo 1975.

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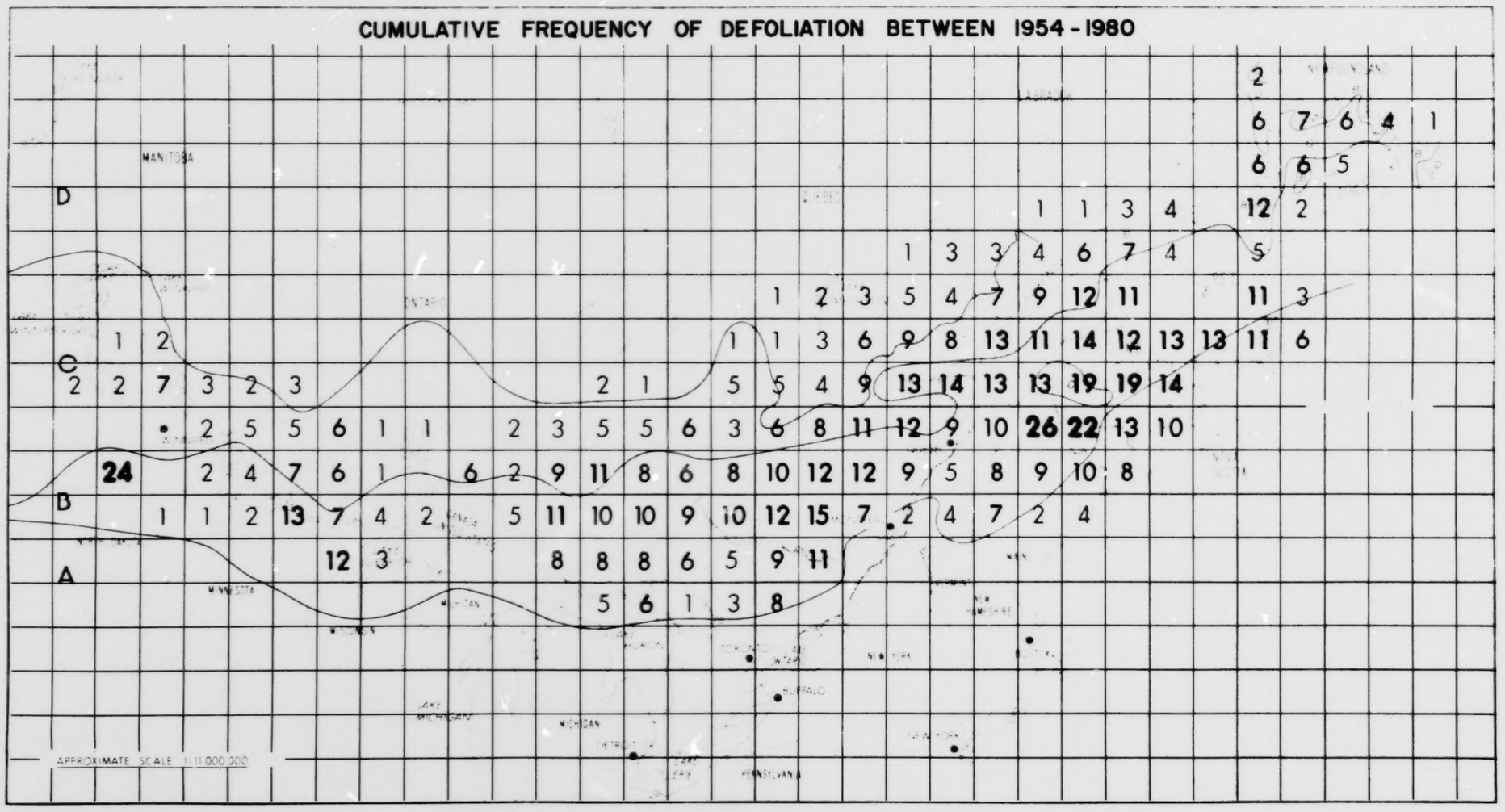
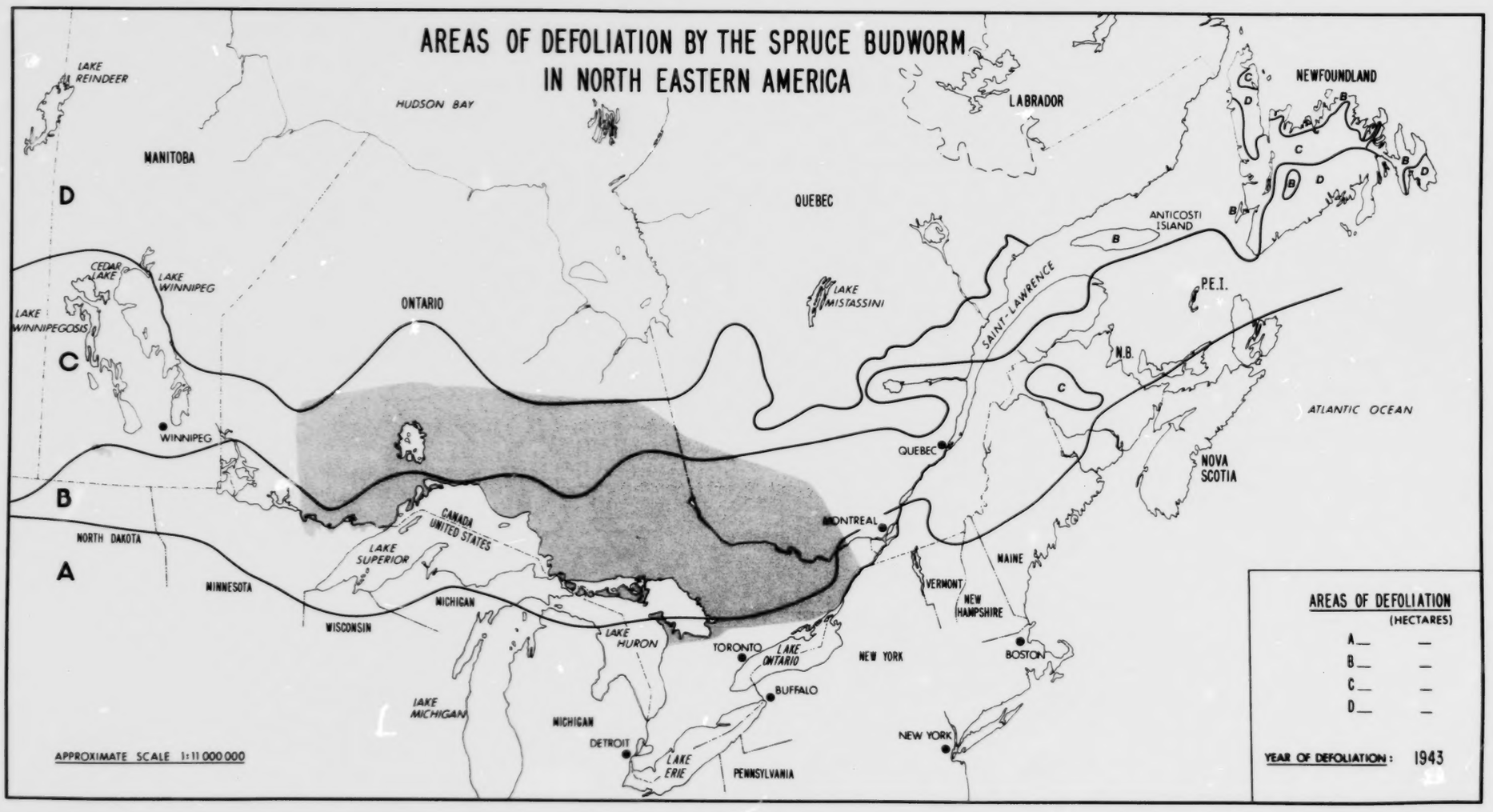
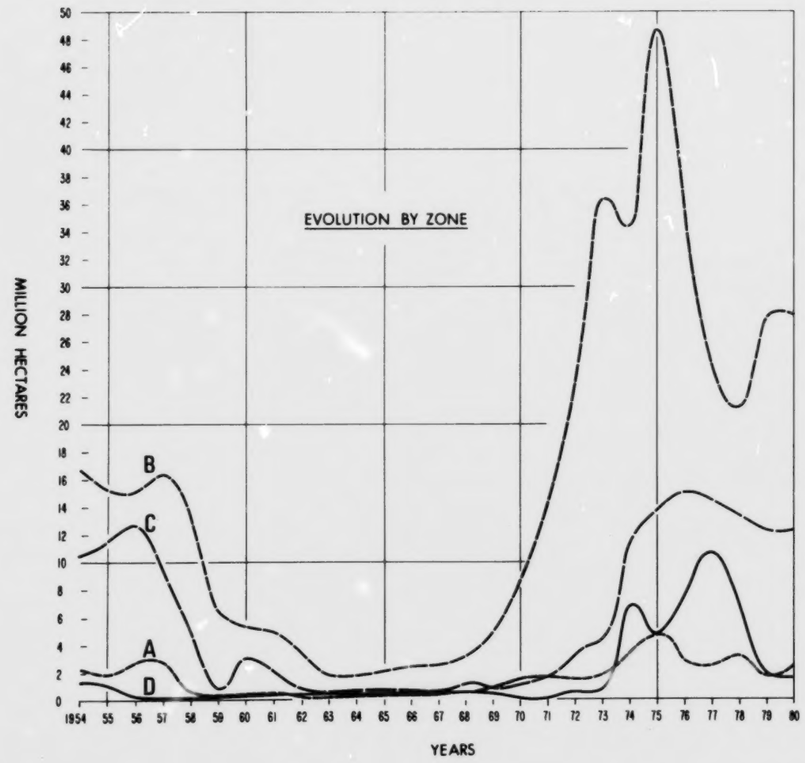
Plate II—Frequency of budworm outbreaks, 1954–80, by grid square for the spruce budworm region, eastern North America.





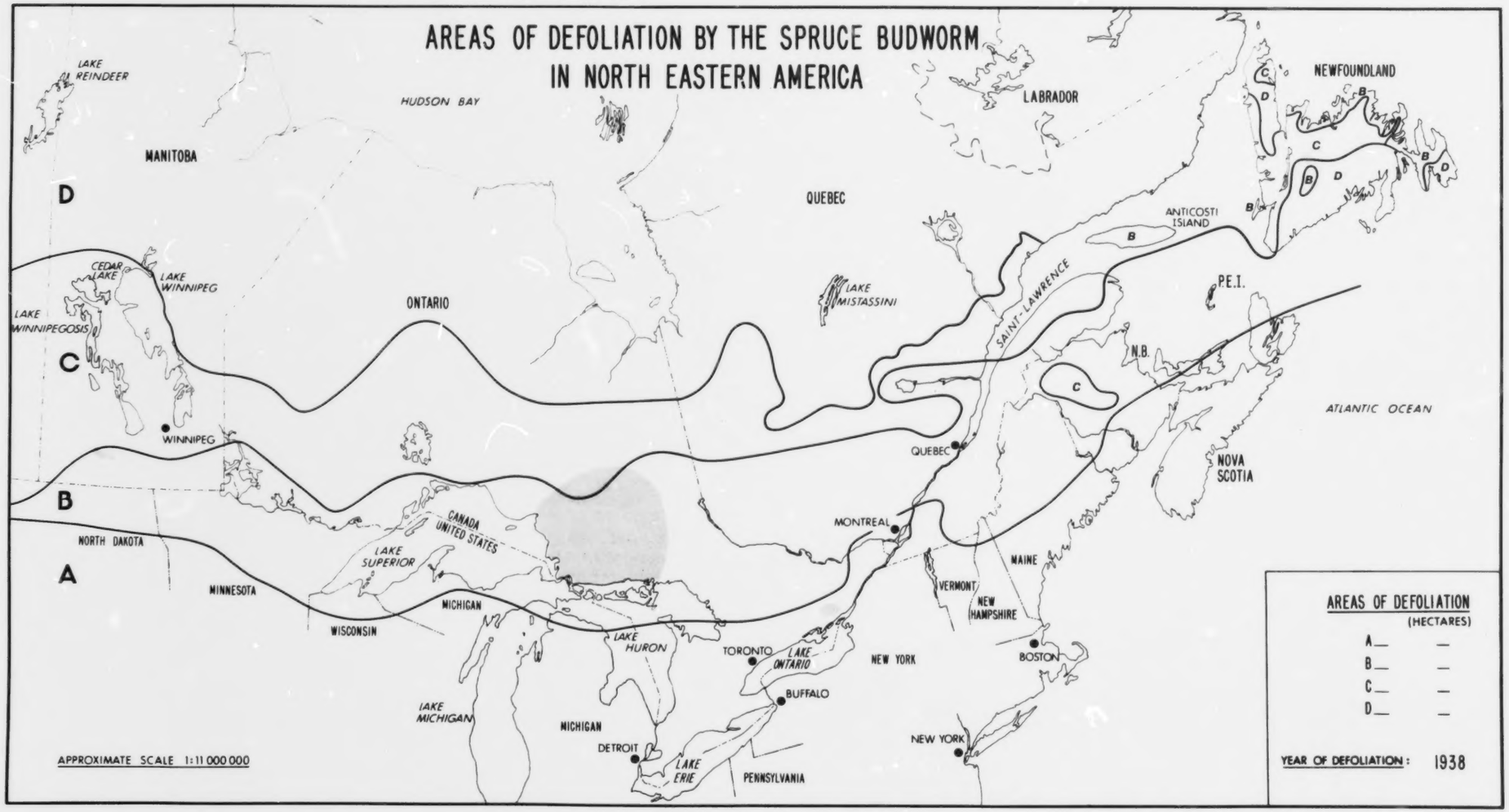
SPRUCE BUDWORM



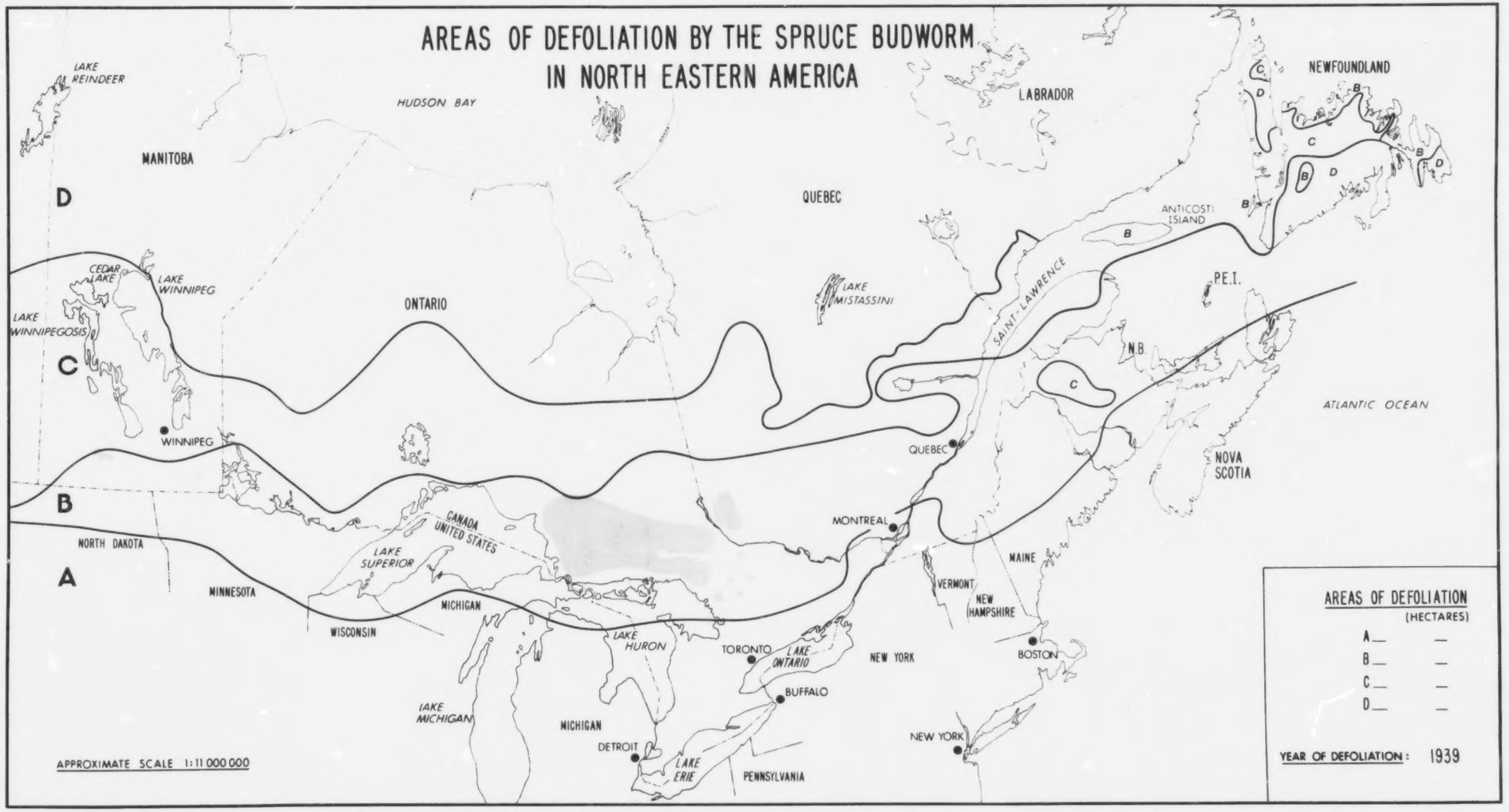
AREAS OF DEFOLIATION
(hectares)

Year of infestation	Zone A	Zone B	Zone C	Zone D
54	2,240,000	16,910,000	10,460,000	1,180,000
55	1,970,000	15,040,000	11,740,000	1,220,000
56	2,840,000	15,880,000	12,780,000	300,000
57	2,860,000	16,350,000	9,046,000	320,000
58	560,000	13,260,000	5,490,000	320,000
59	360,000	6,460,000	800,000	230,000
60	220,000	5,320,000	2,900,000	360,000
61	550,000	5,010,000	2,140,000	400,000
62	130,000	3,020,000	880,000	450,000
63	220,000	1,600,000	370,000	310,000
64	270,000	1,900,000	640,000	770,000
65	190,000	1,980,000	550,000	570,000
66	400,000	2,400,000	380,000	450,000
67	190,000	2,580,000	670,000	400,000
68	260,000	3,160,000	1,140,000	500,000
69	770,000	4,900,000	730,000	760,000
70	1,530,000	8,130,000	1,200,000	70,000
71	1,540,000	13,860,000	1,580,000	0
72	1,510,000	21,130,000	3,330,000	690,000
73	1,630,000	36,190,000	4,140,000	590,000
74	3,380,000	34,550,000	11,500,000	6,970,000
75	4,900,000	48,840,000	13,630,000	4,710,000
76	2,850,000	36,990,000	15,060,000	7,860,000
77	2,490,000	24,300,000	14,230,000	10,890,000
78	3,290,000	21,415,000	13,670,000	6,710,000
79	1,570,000	28,340,000	12,120,000	1,910,000
80	2,440,000	28,346,000	12,430,000	1,880,000

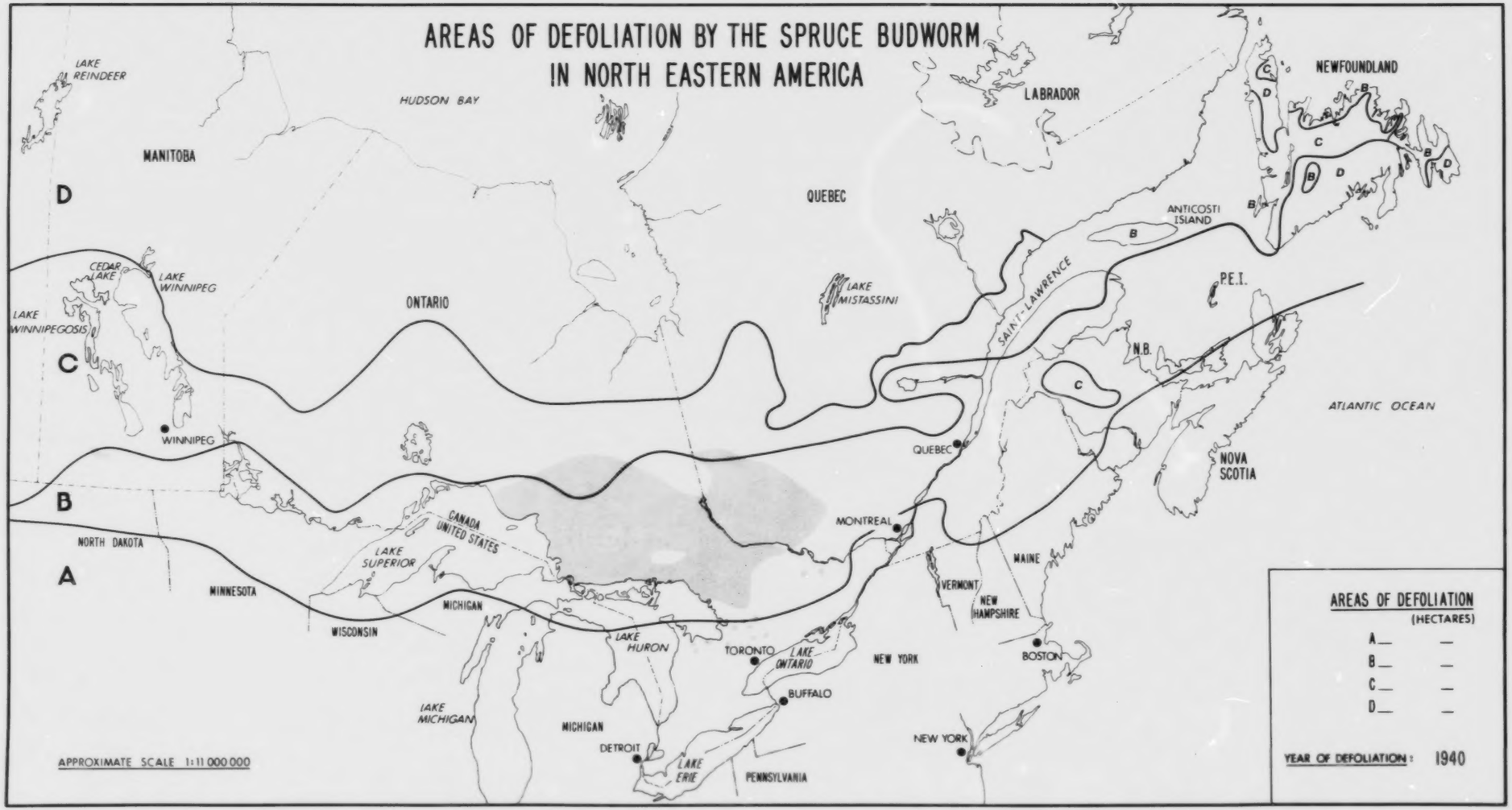
Plates III–XLV Spruce budworm annual defoliation maps, 1938–80.



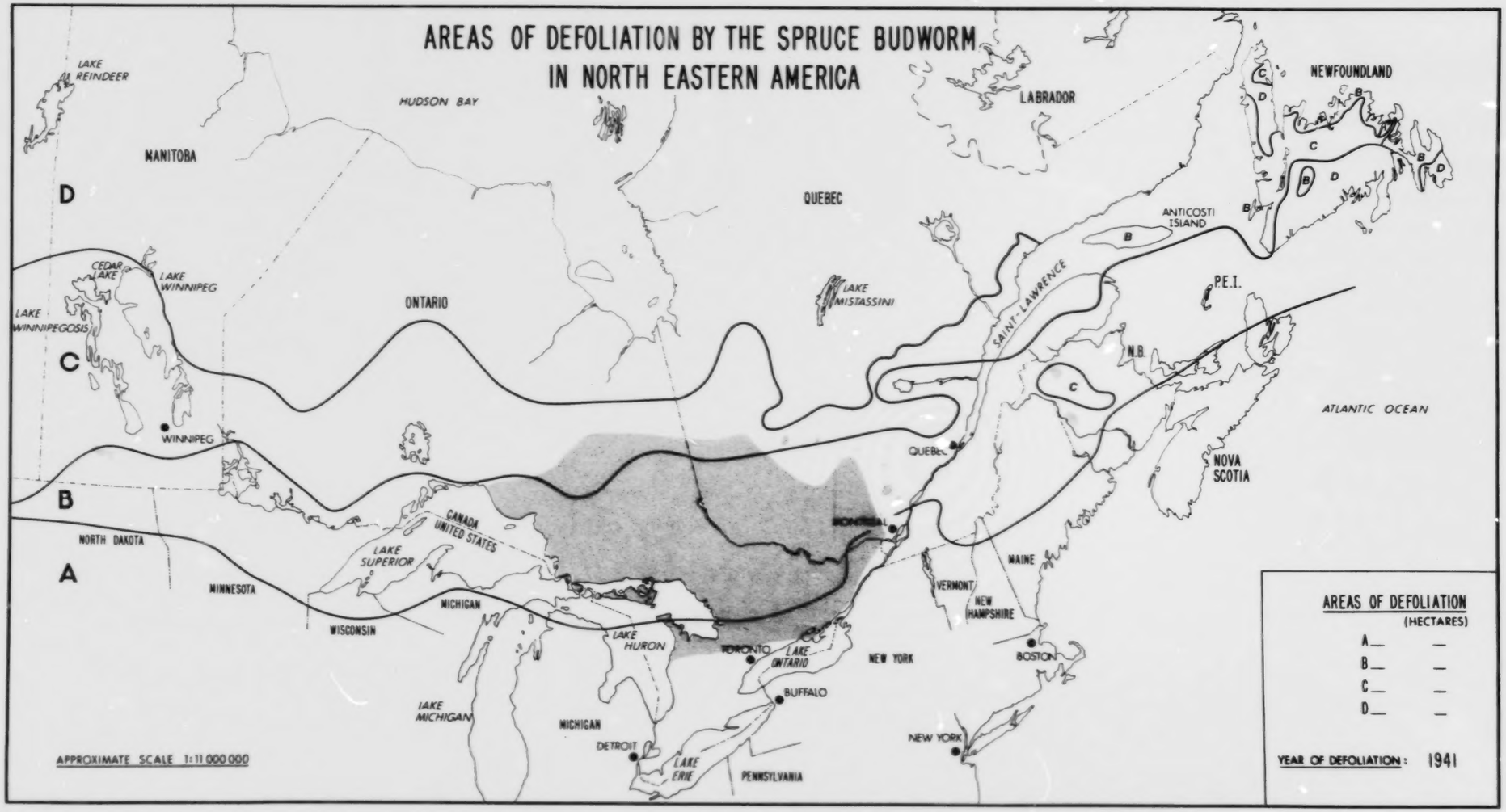
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



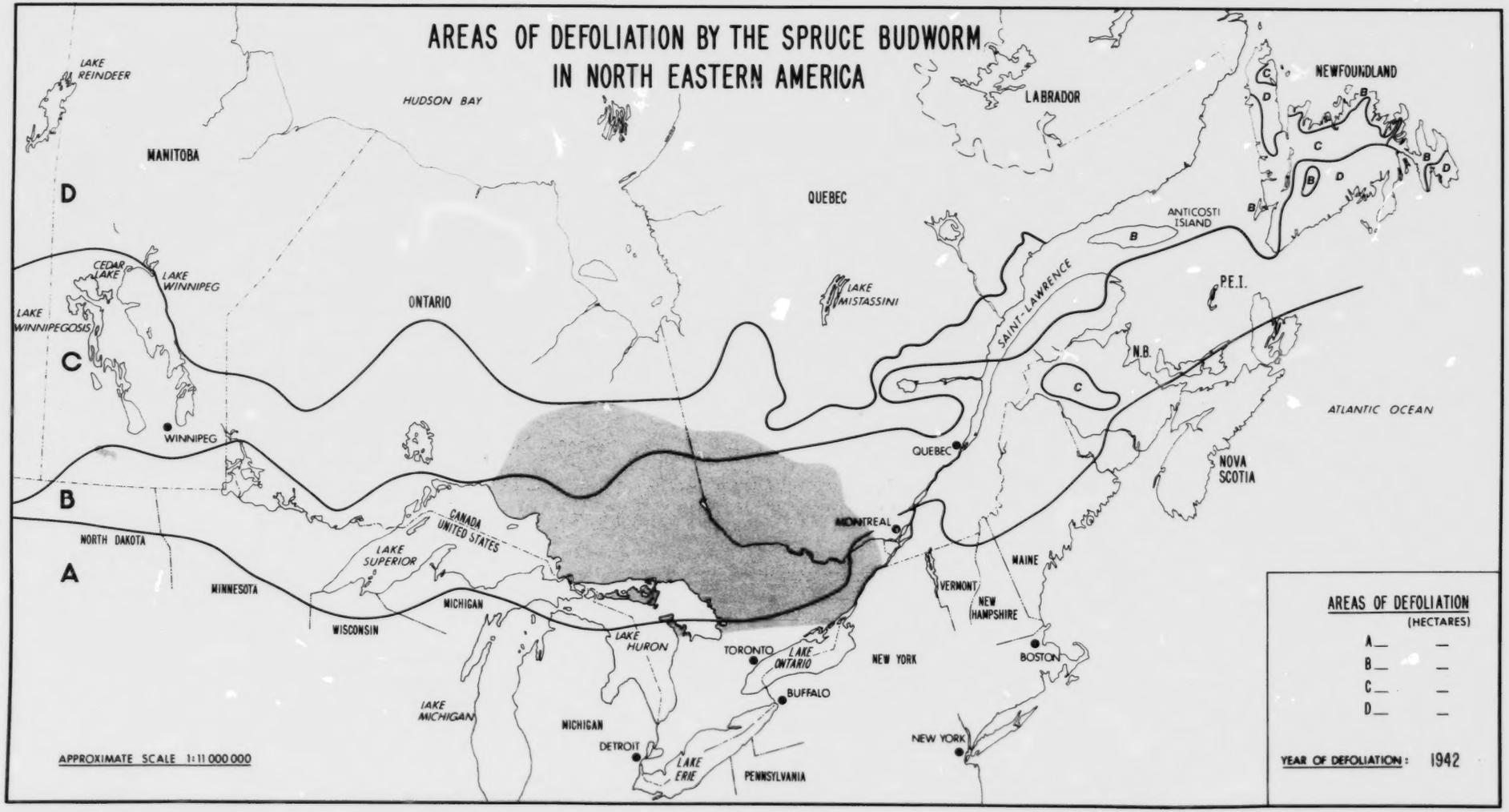
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



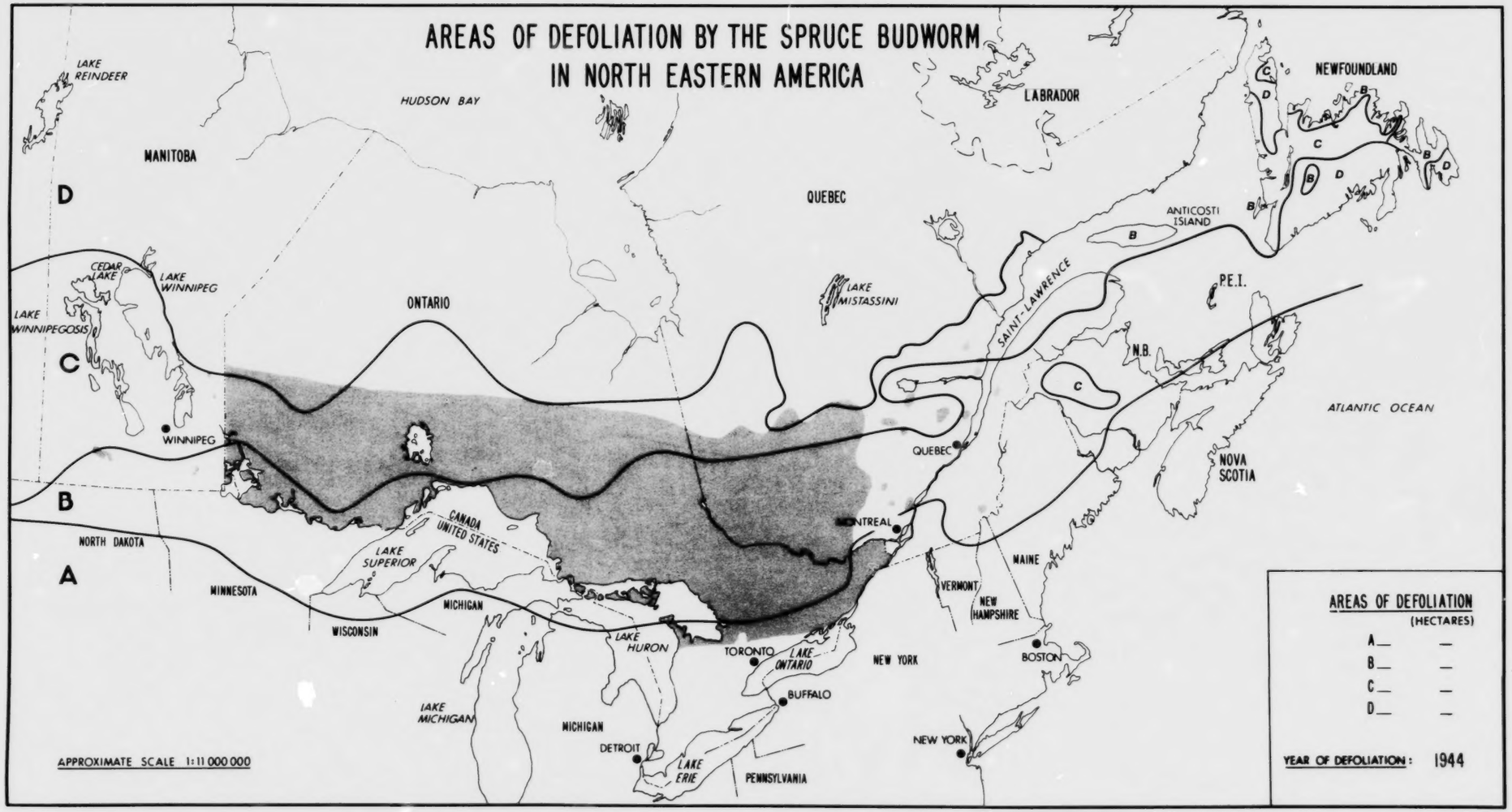
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



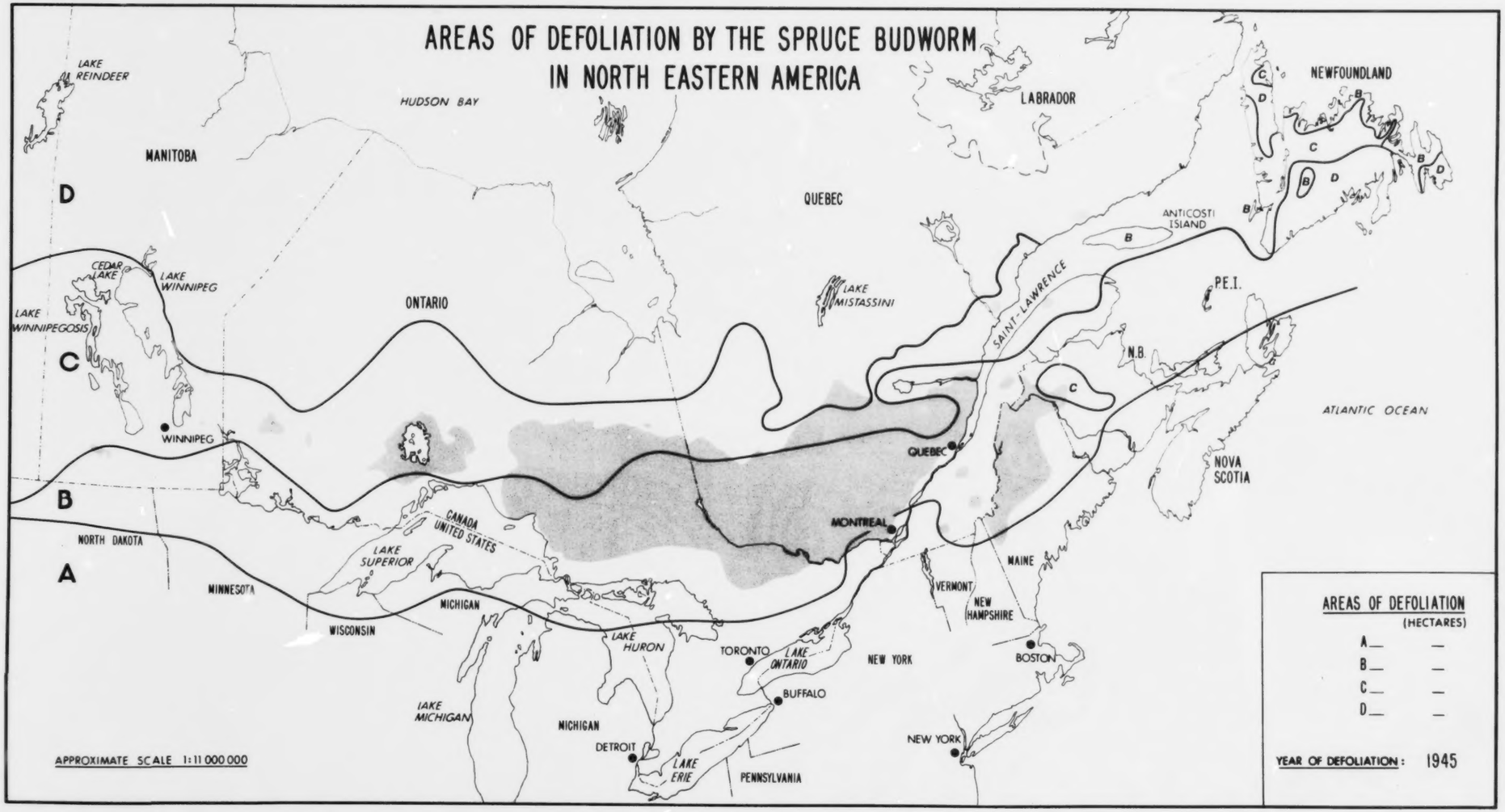
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



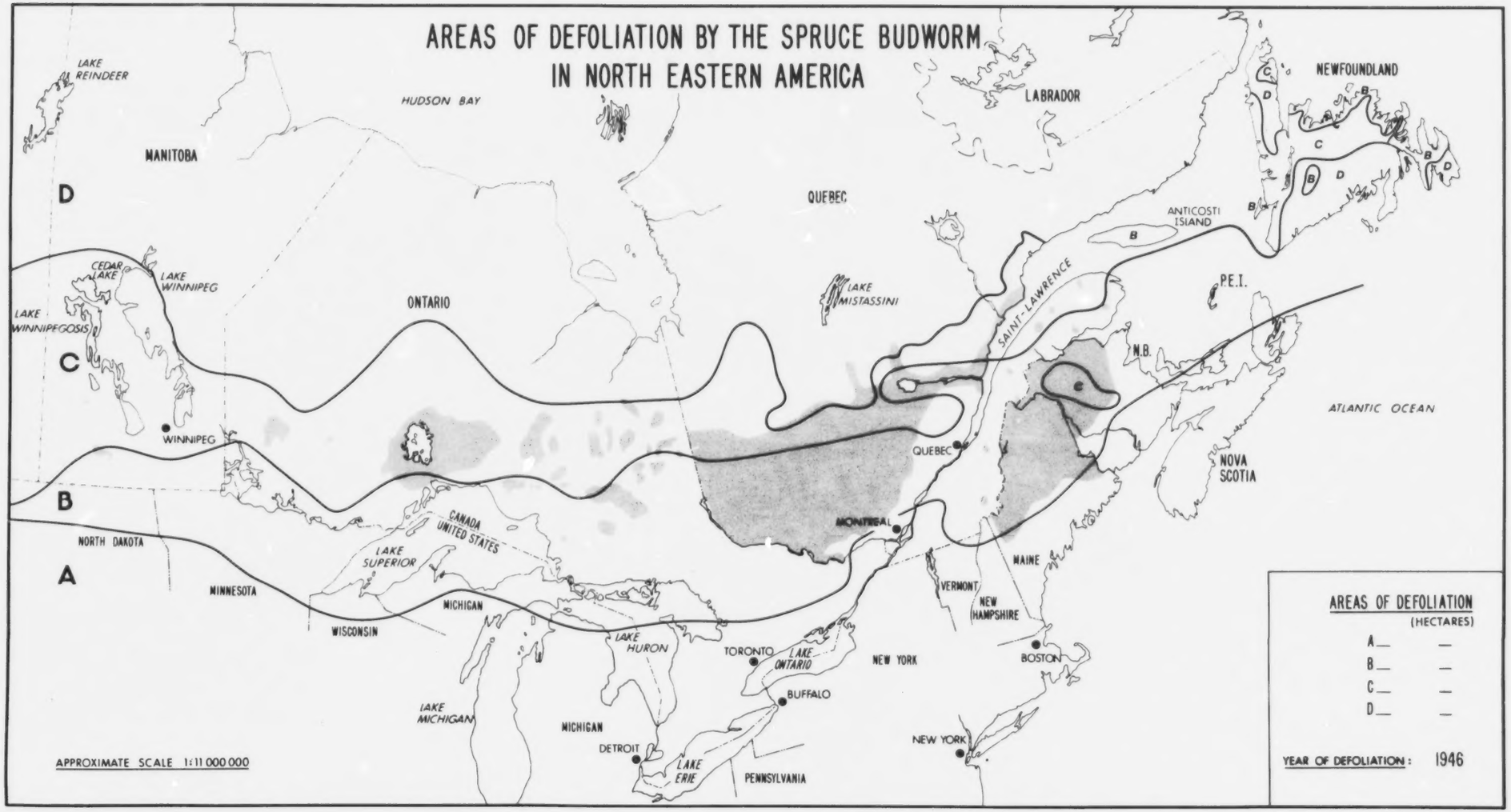
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



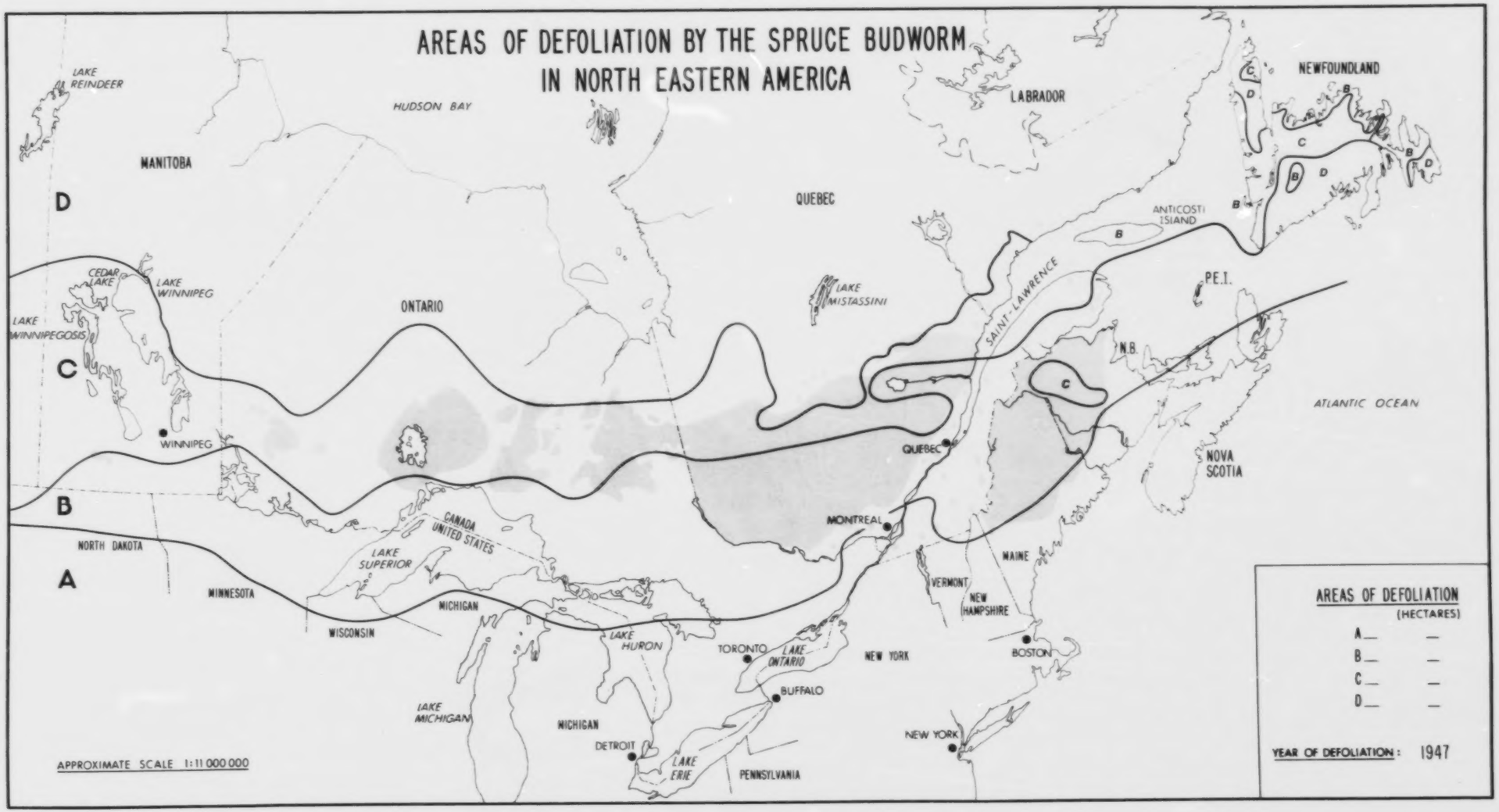
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



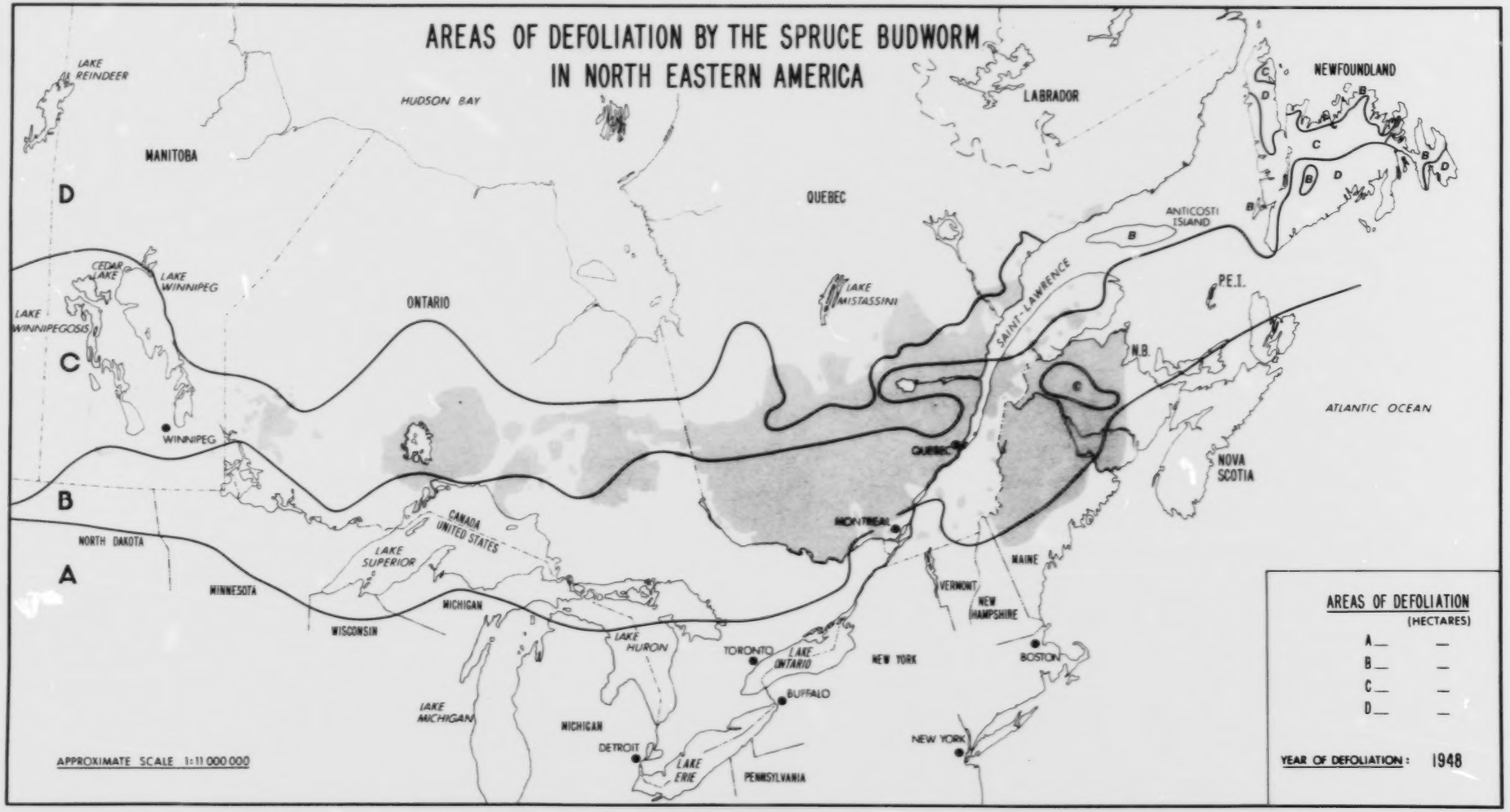
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



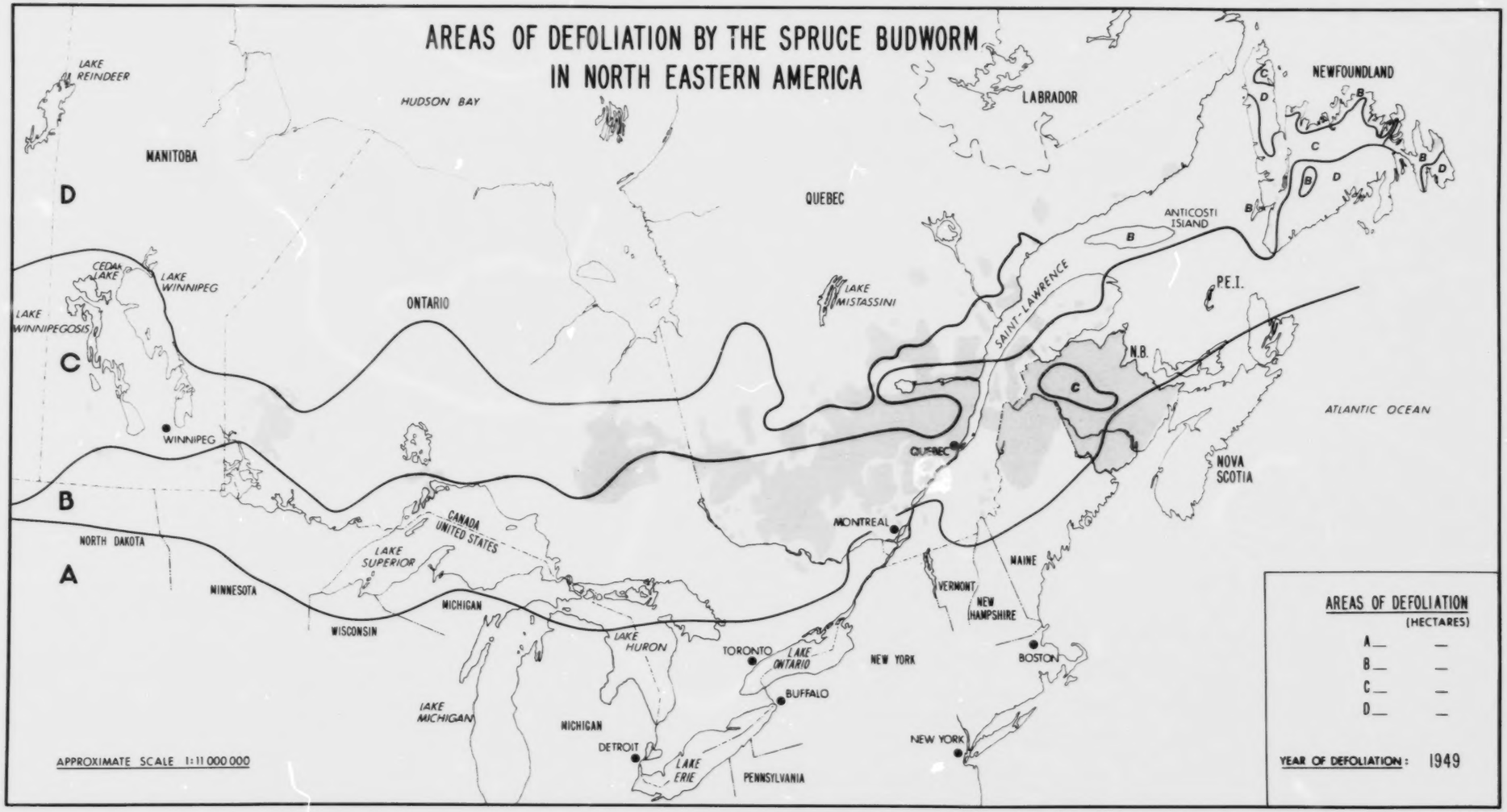
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



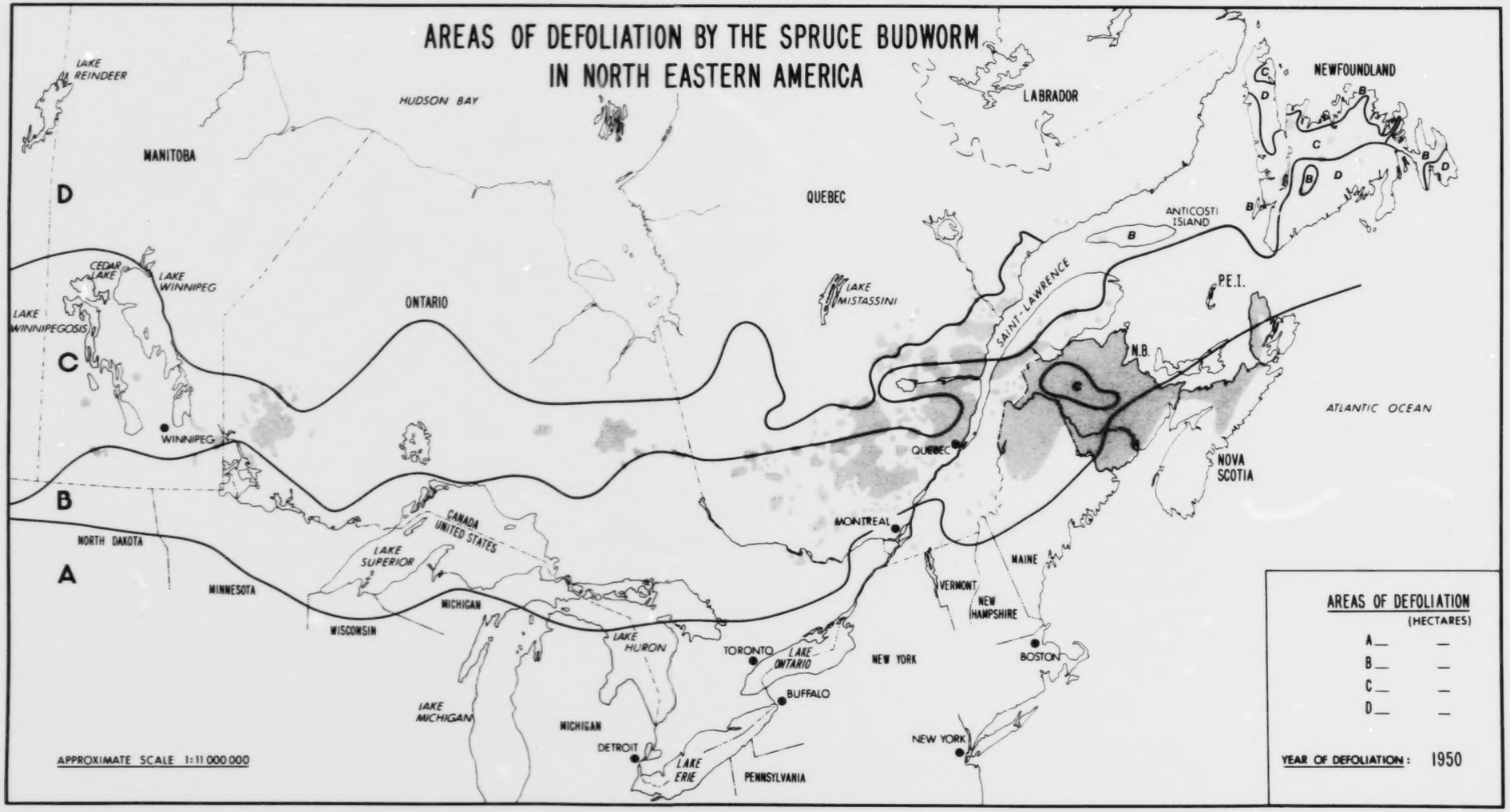
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



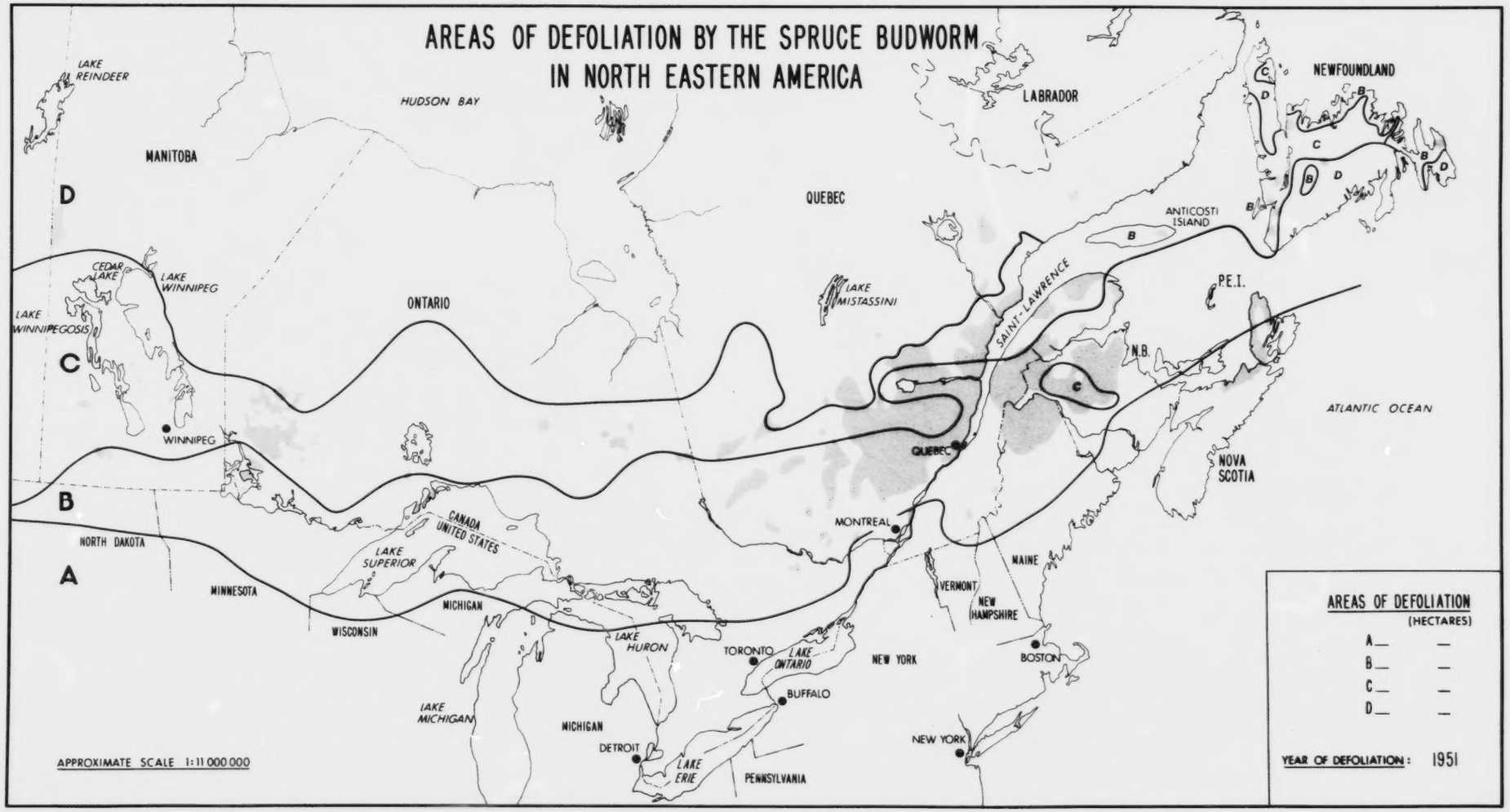
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



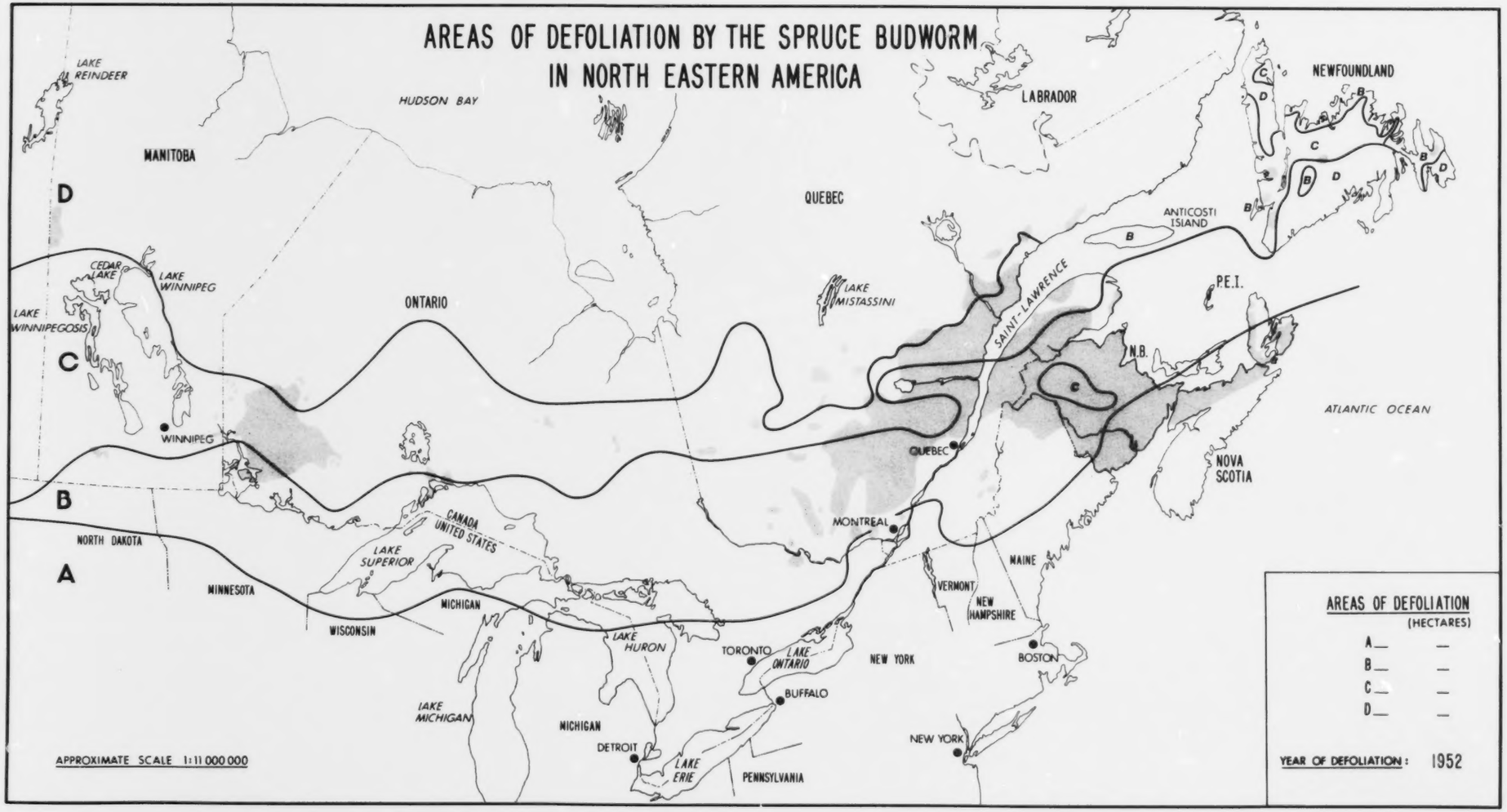
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



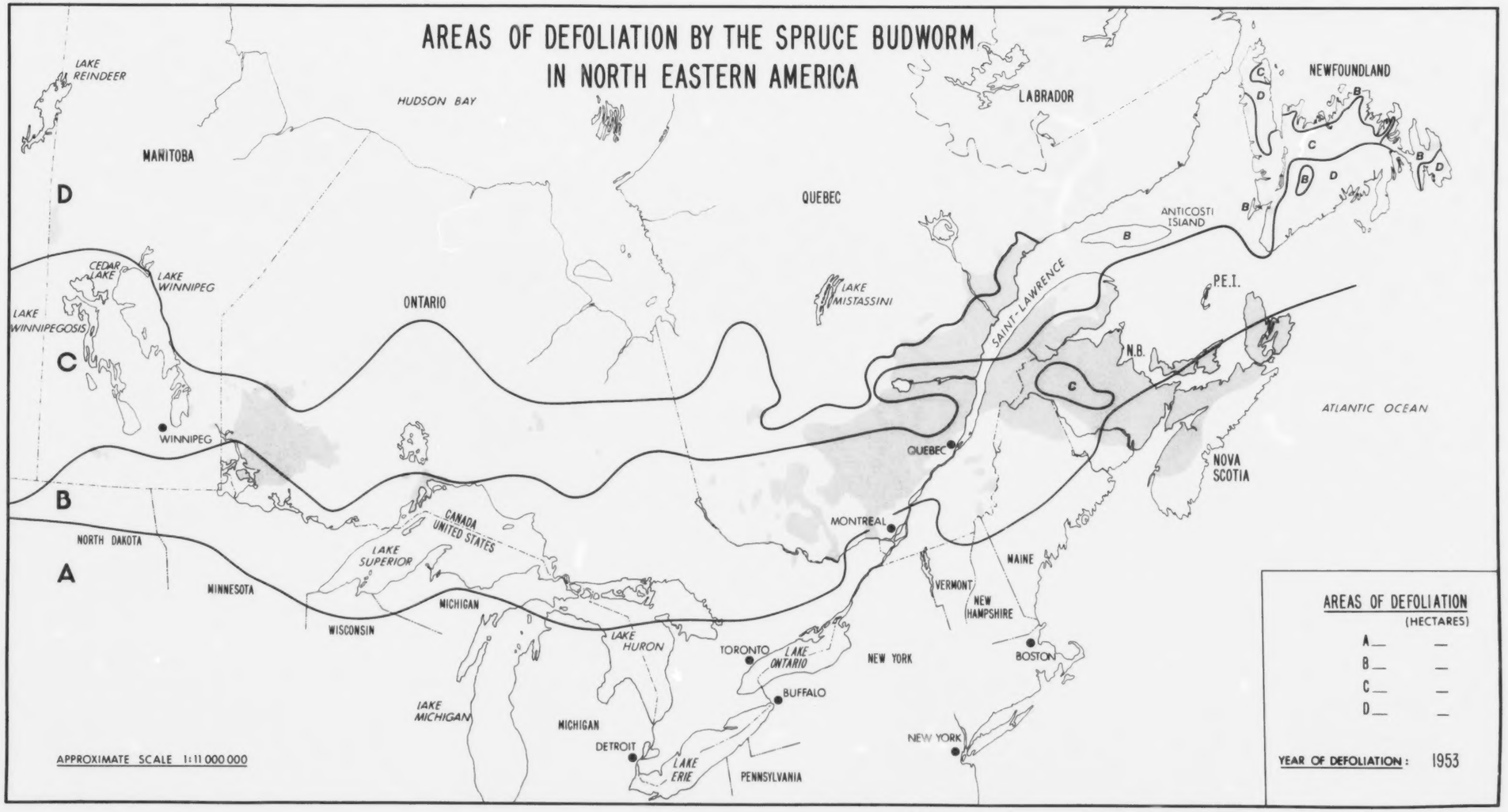
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



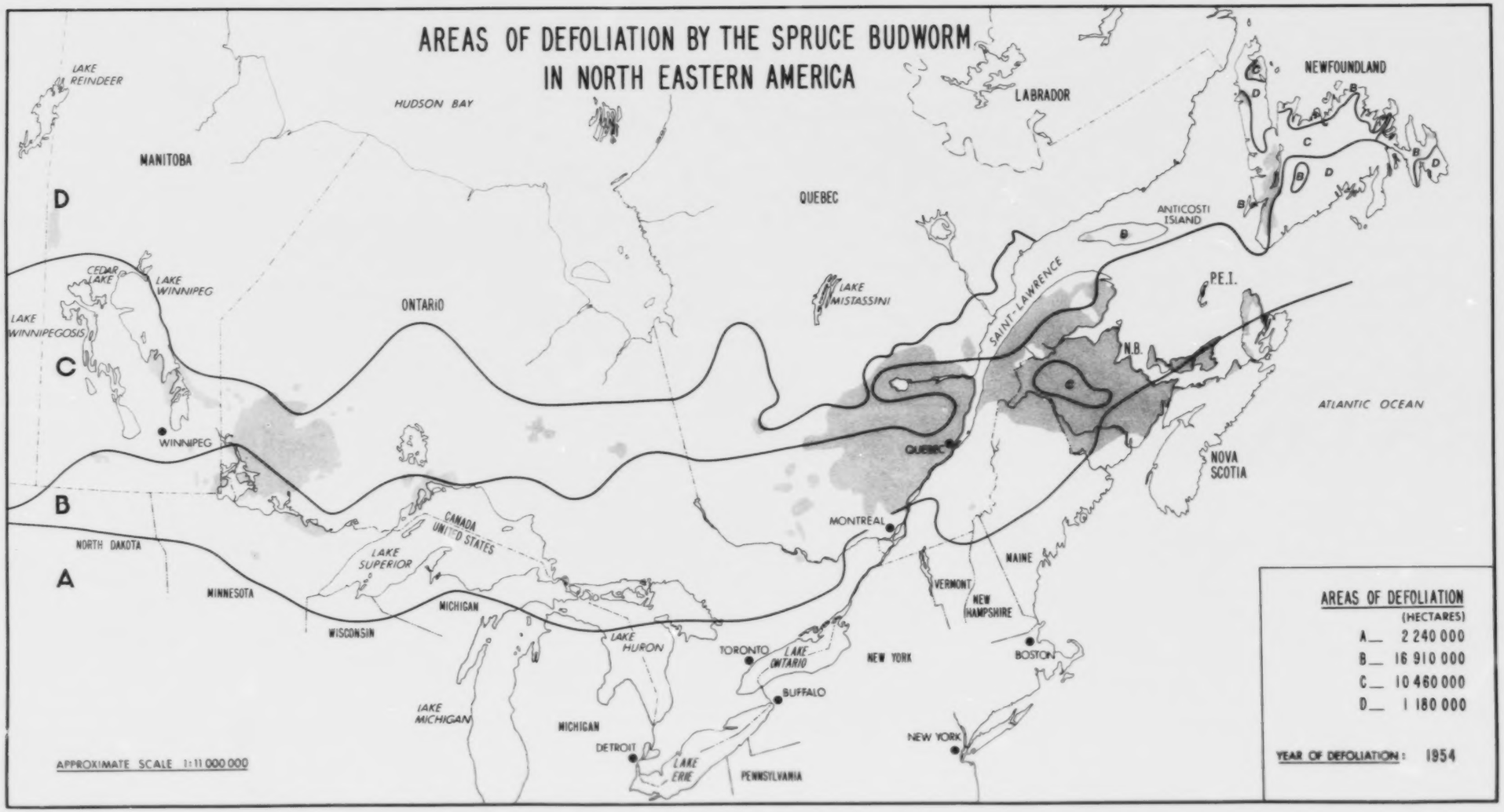
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



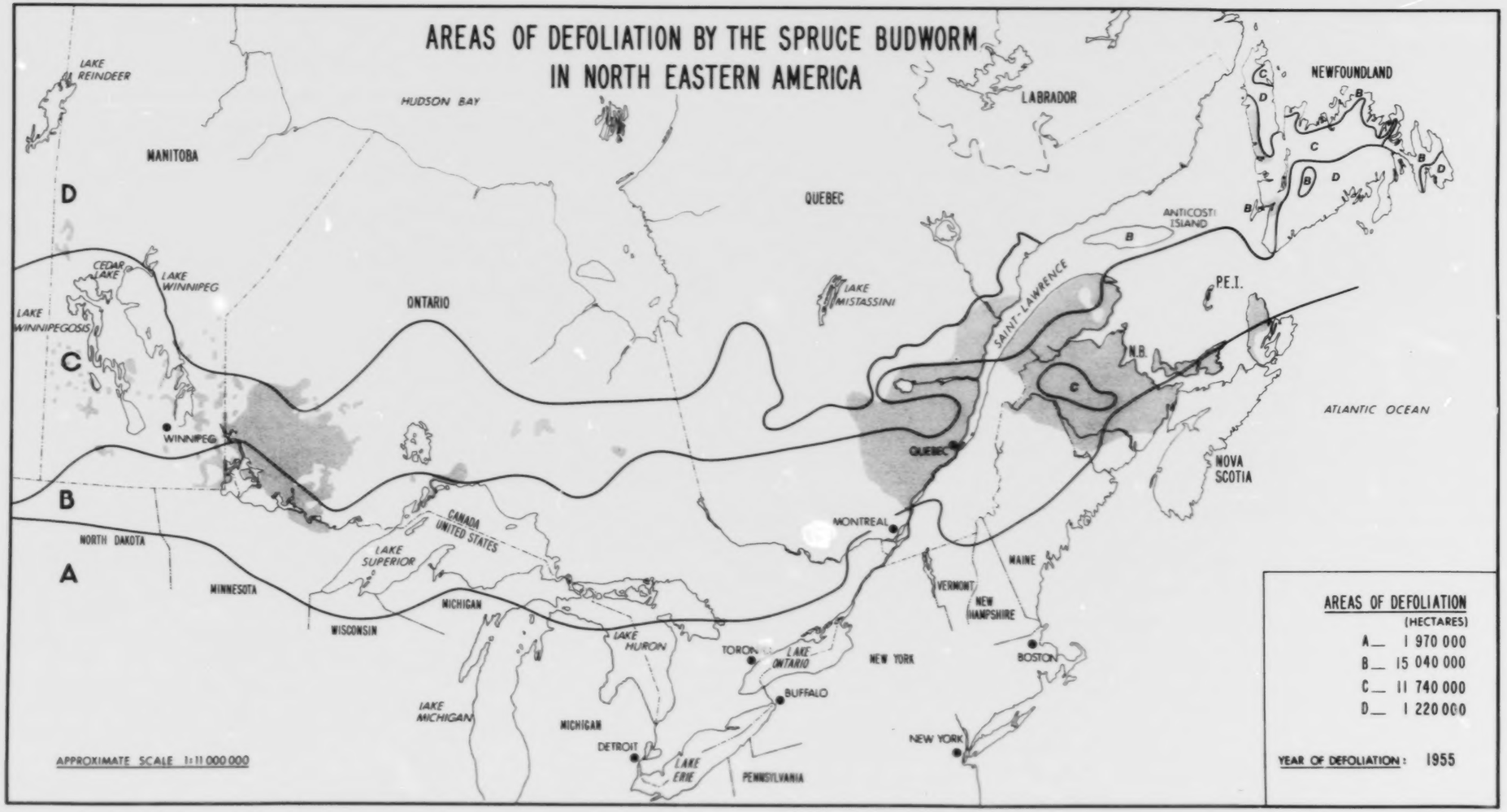
APPROXIMATE SCALE 1:11 000 000

AREAS OF DEFOLIATION
(HECTARES)

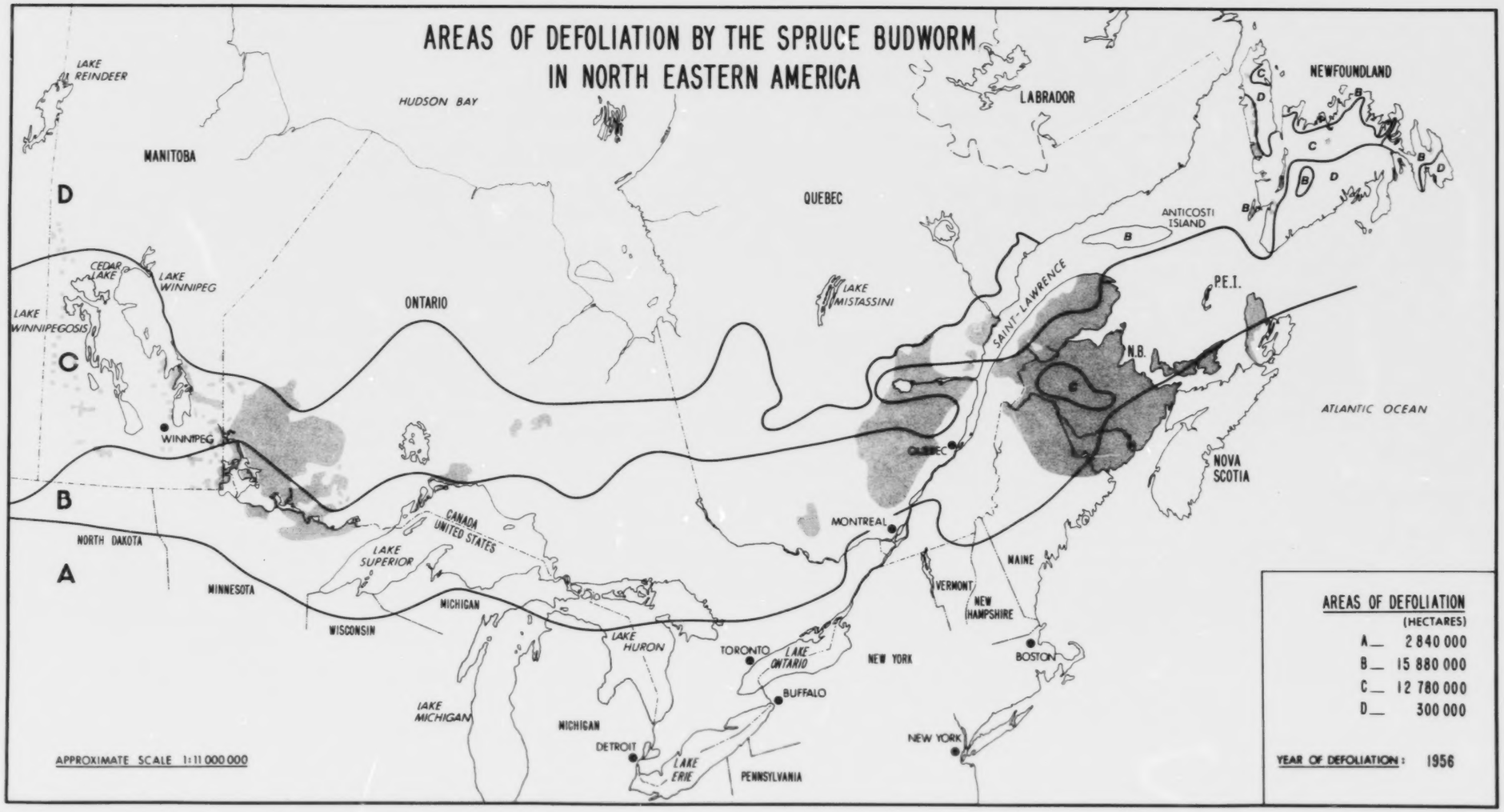
A__	2 240 000
B__	16 910 000
C__	10 460 000
D__	1 180 000

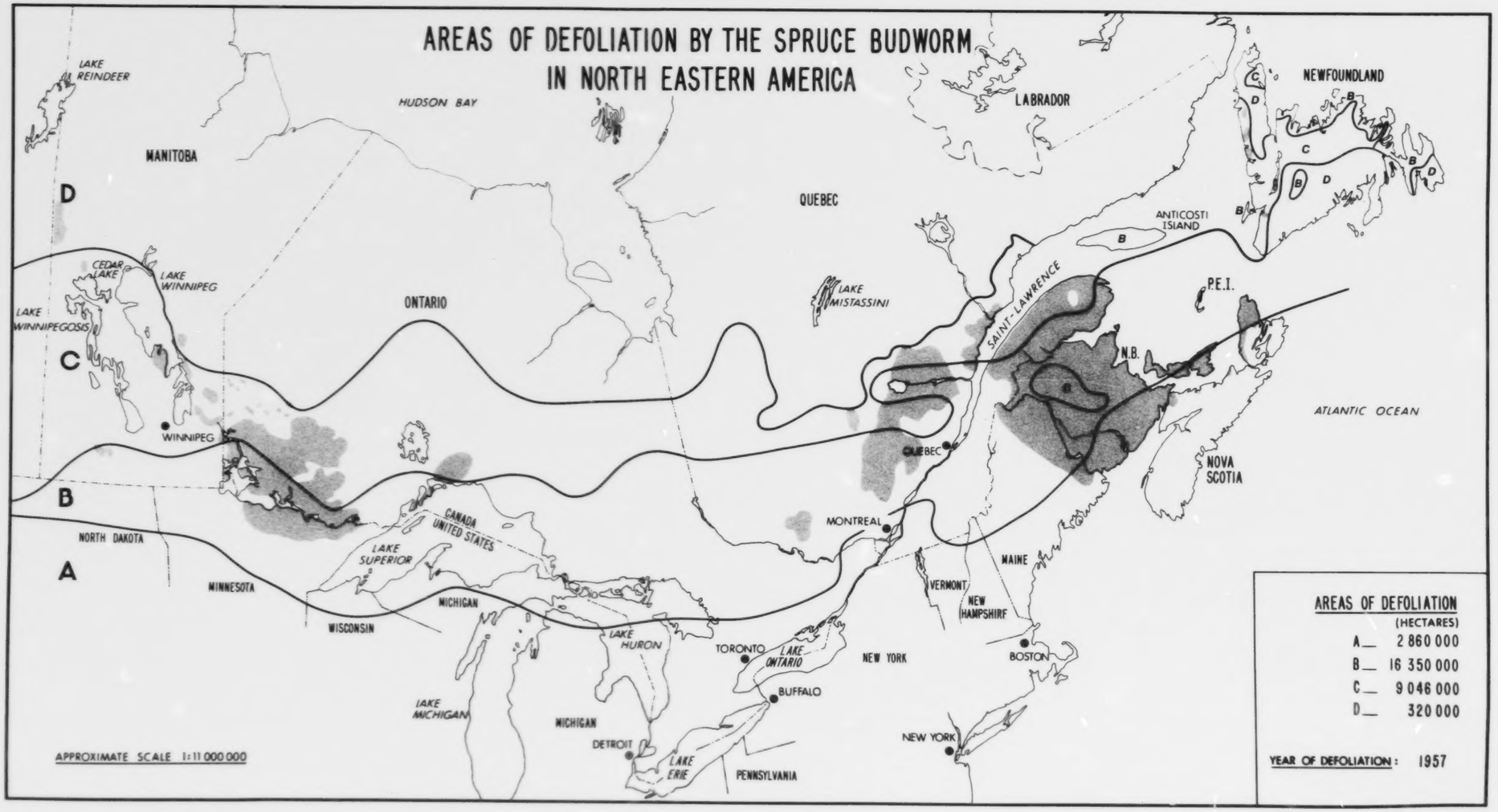
YEAR OF DEFOLIATION: 1954

AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA

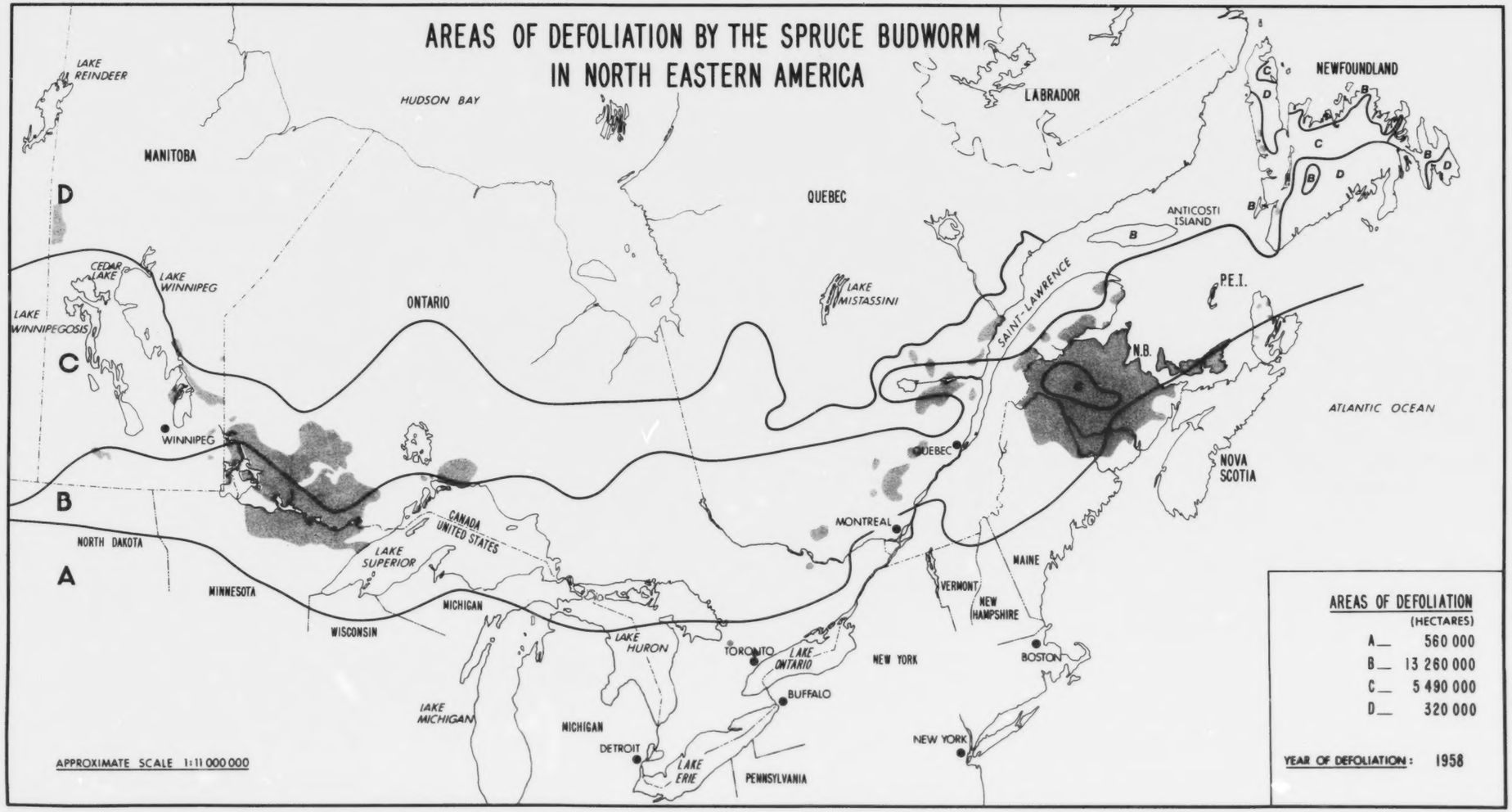


AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA

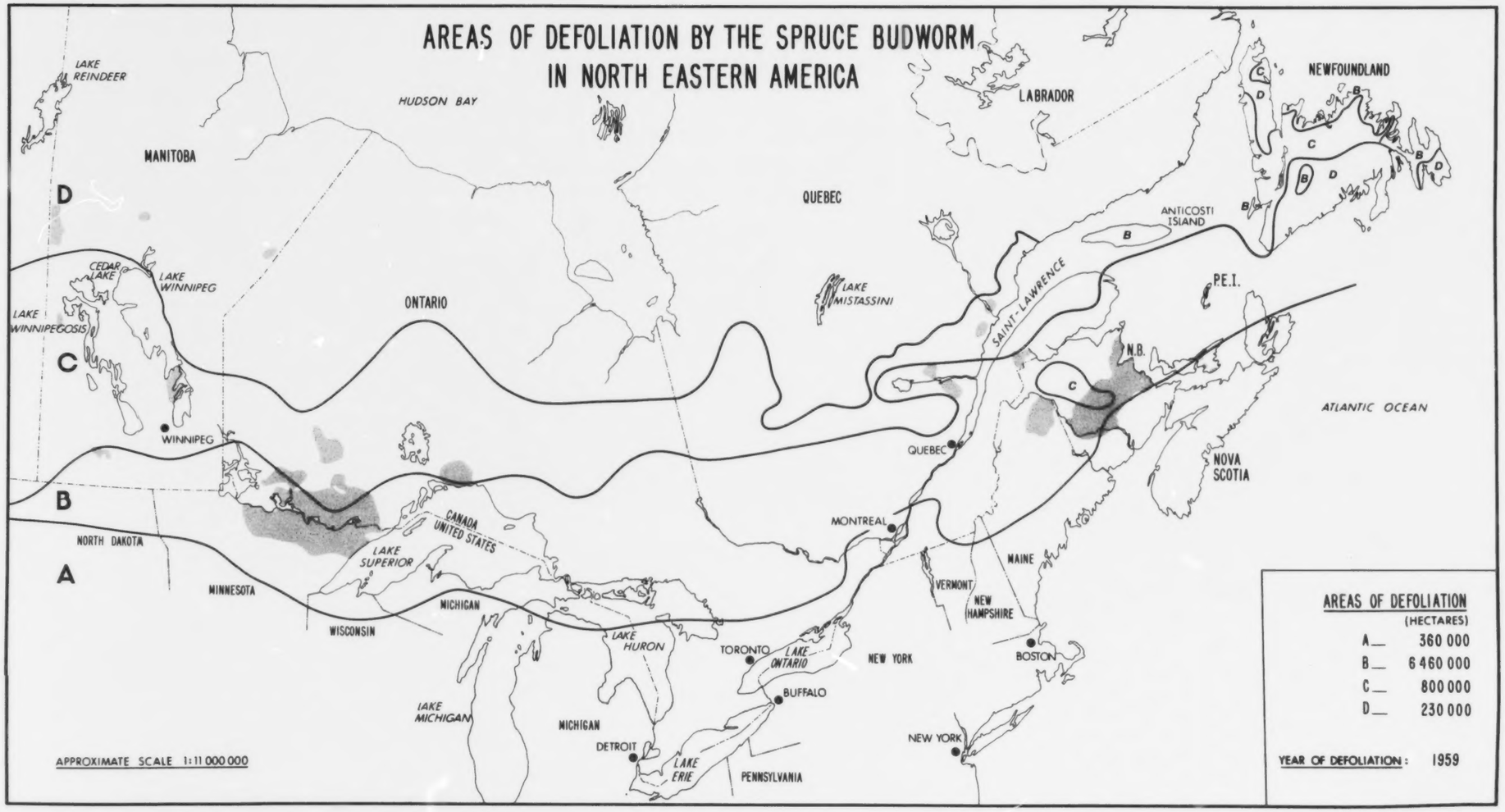



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM
IN NORTH EASTERN AMERICA
LAKE REINDEER
HUDSON BAY
MANITOBA
QUEBEC
LABRADOR
NEWFOUNDLAND
ANTICOSTI ISLAND
CEDAR LAKE
LAKE WINNIPEG
LAKE WINNIPEGOSIS
ONTARIO
LAKE MISTASSINI
SAINT-LAWRENCE
P.E.I.
N.B.
ATLANTIC OCEAN
WINNIPEG
QUEBEC
NOVA SCOTIA
MONTREAL
CANADA
UNITED STATES
NORTH DAKOTA
LAKE SUPERIOR
MINNESOTA
MICHIGAN
WISCONSIN
LAKE HURON
TORONTO
LAKE ONTARIO
NEW YORK
BUFFALO
MAINE
VERMONT
NEW HAMPSHIRF
BOSTON
LAKE MICHIGAN
MICHIGAN
DETROIT
LAKE ERIE
PENNSYLVANIA
NEW YORK
A
B
C
D
APPROXIMATE SCALE 1:11 000 000
AREAS OF DEFOLIATION
(HECTARES)
A__ 2 860 000
B__ 16 350 000
C__ 9 046 000
D__ 320 000
YEAR OF DEFOLIATION: 1957

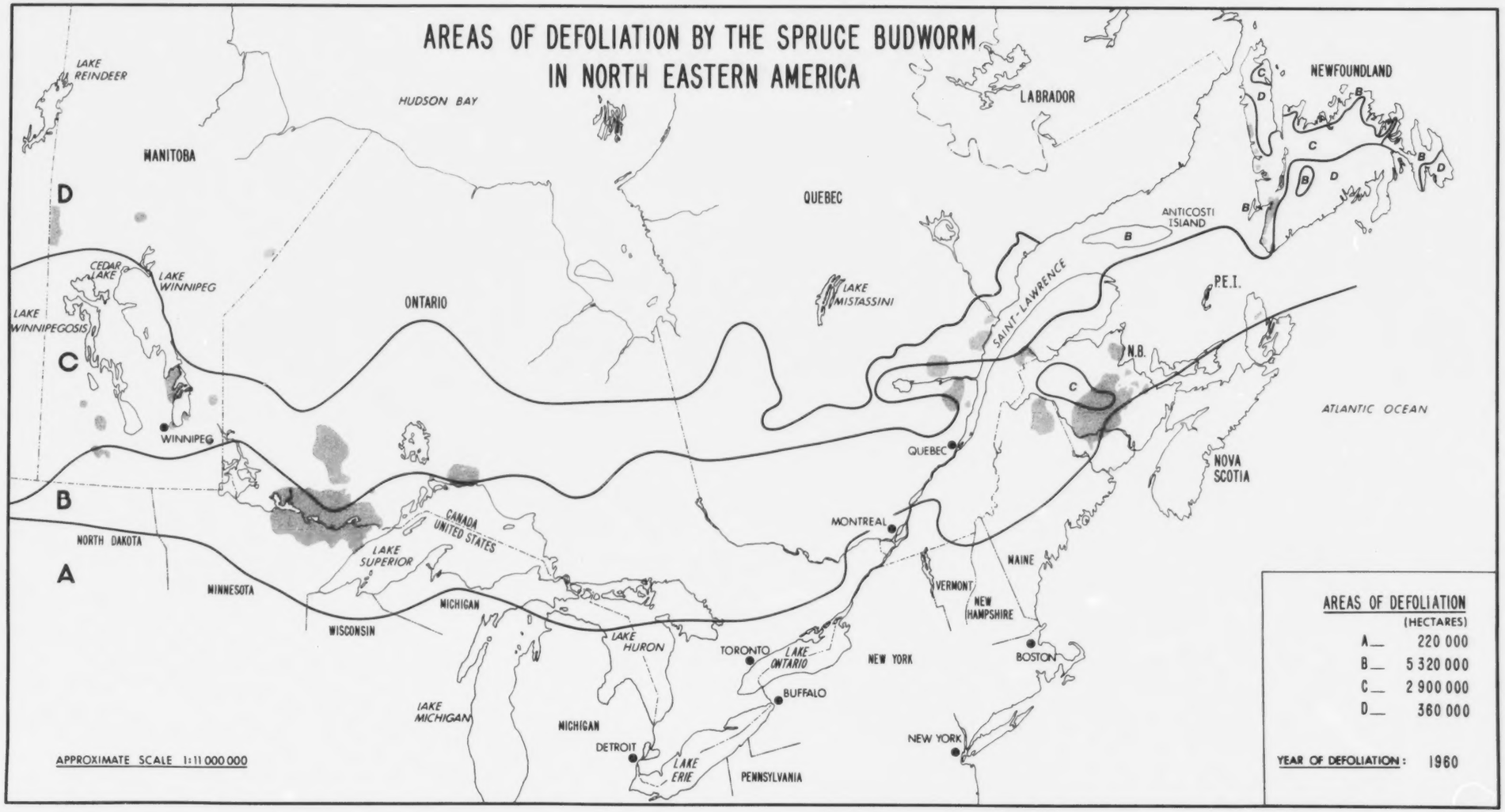
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



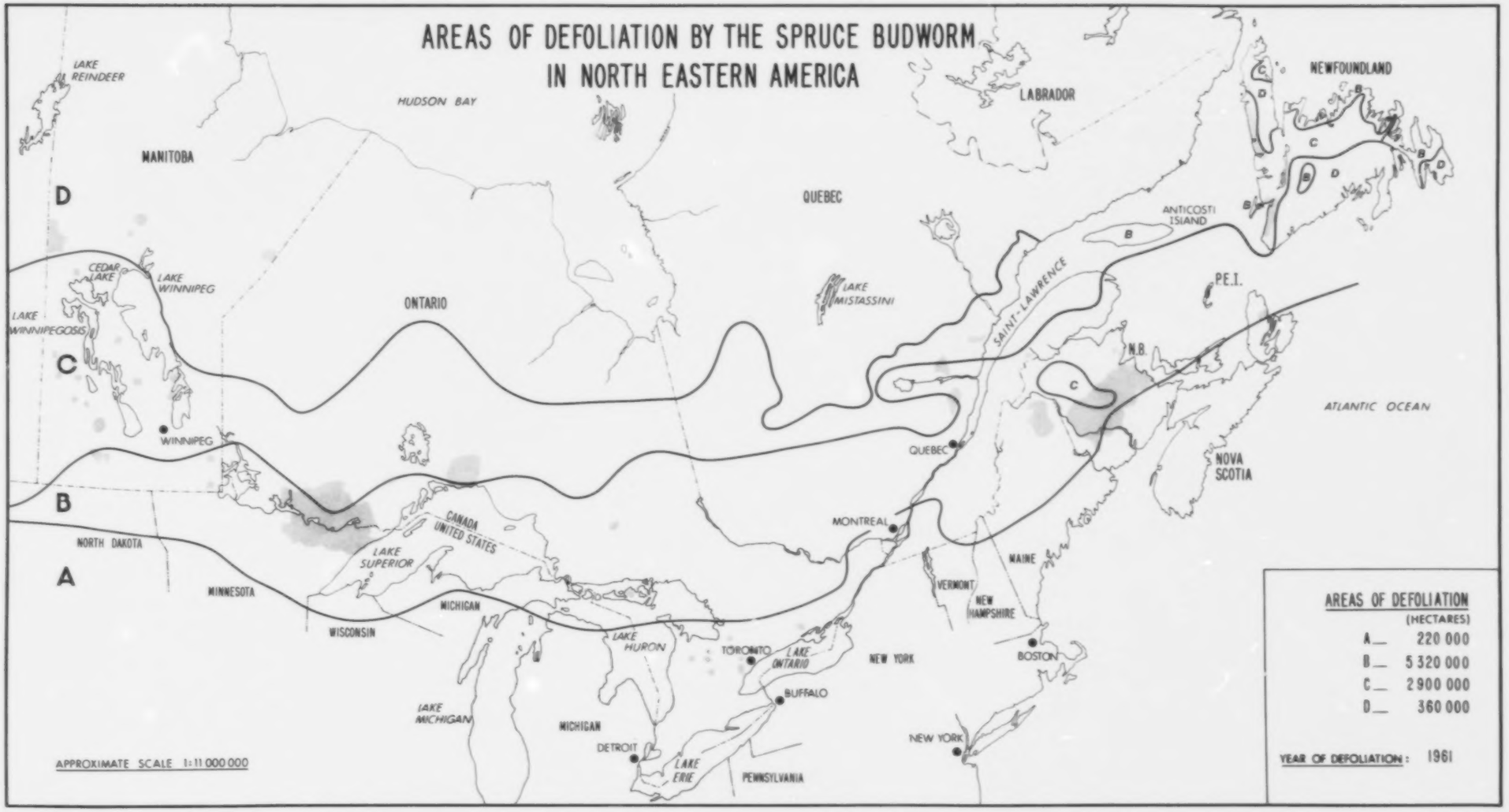
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



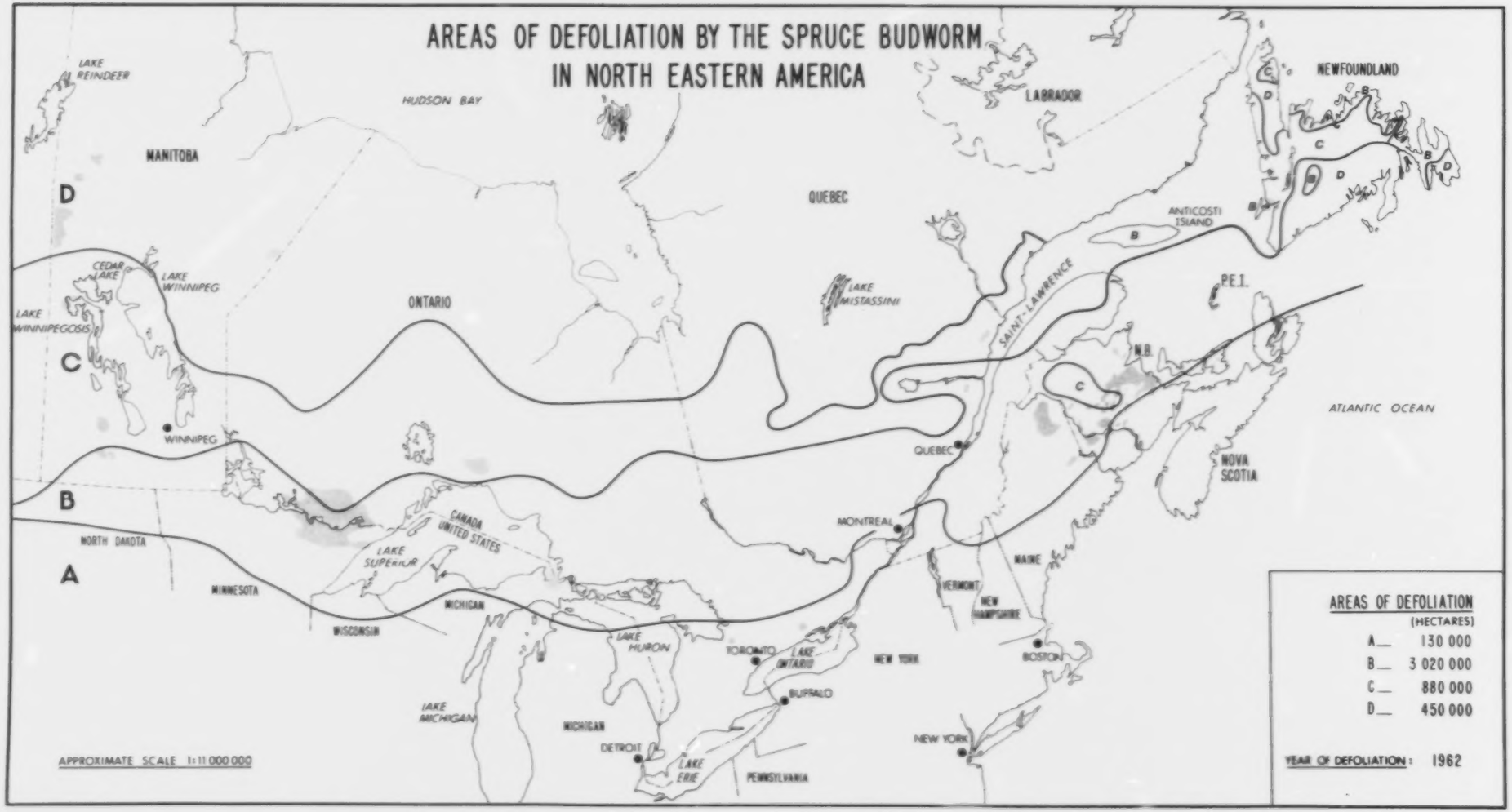
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



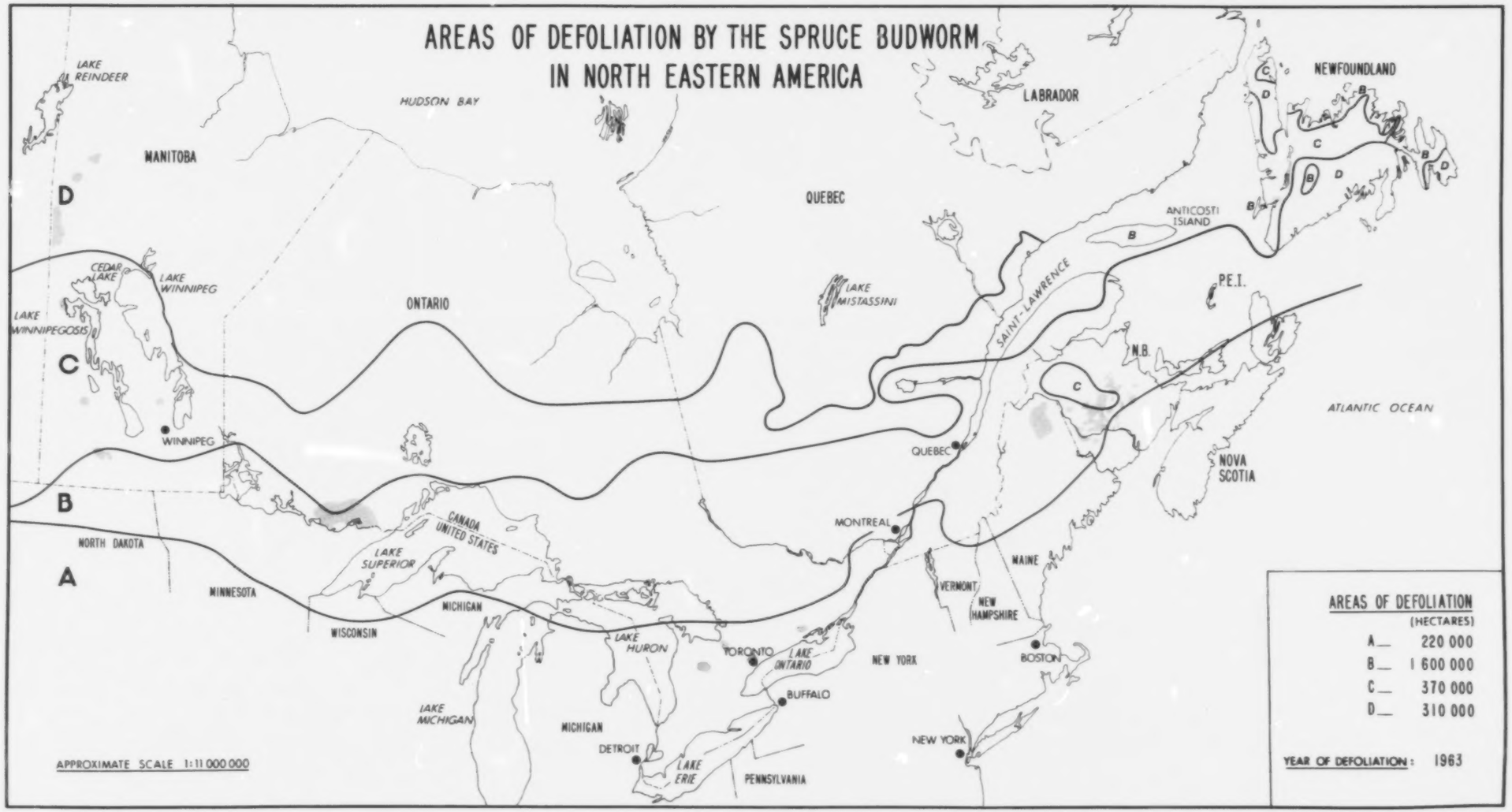
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



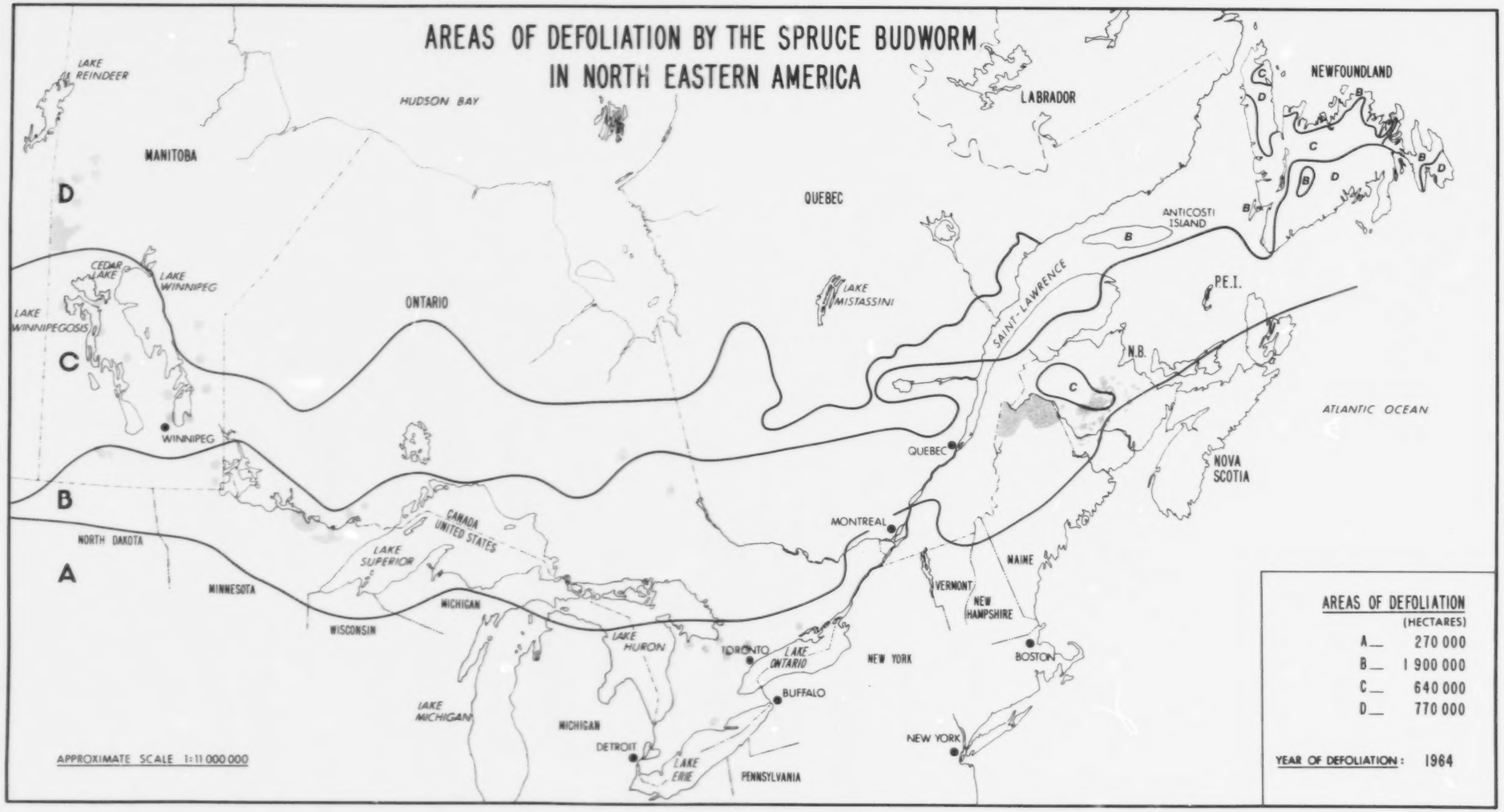
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



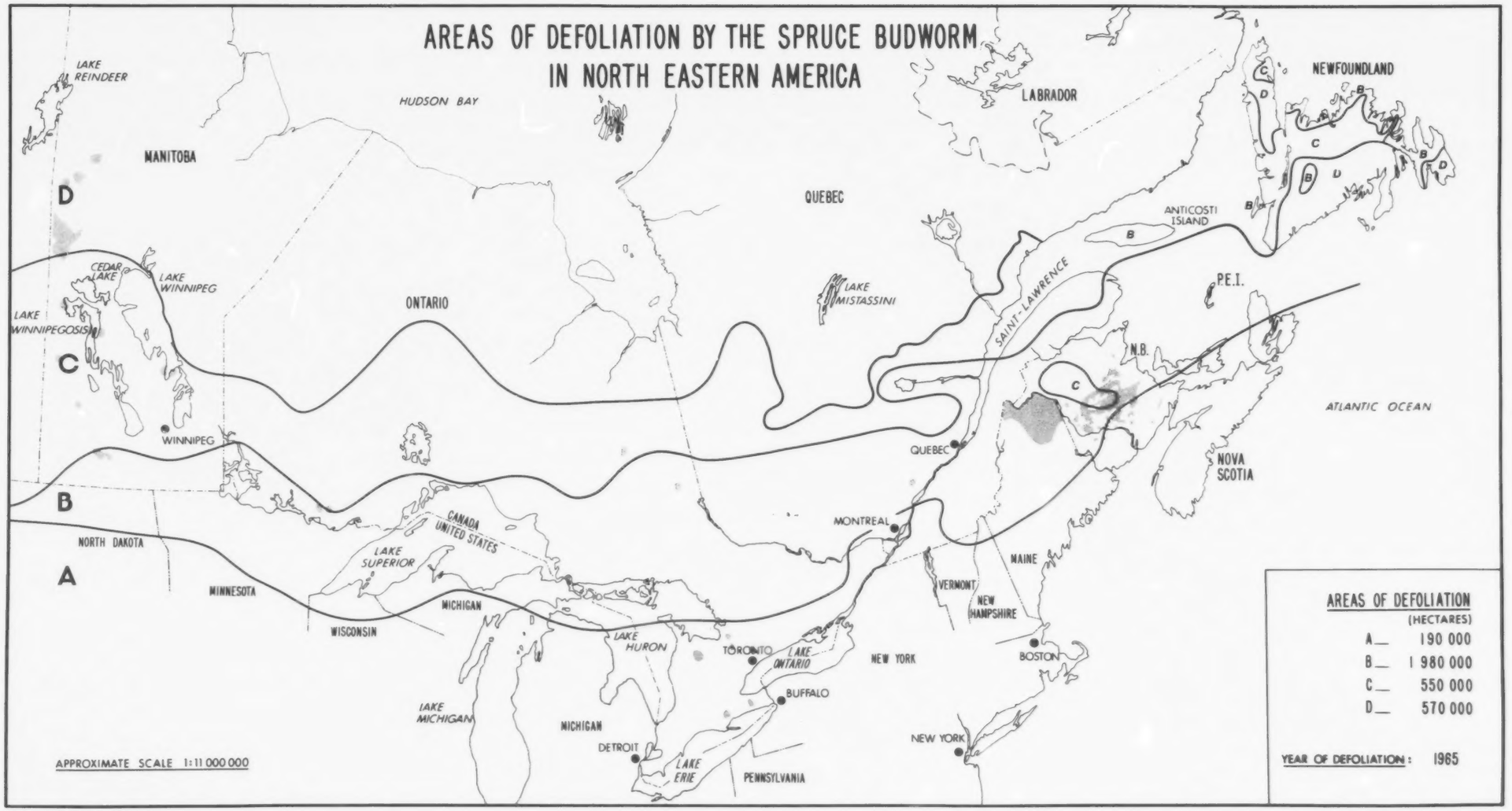
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



APPROXIMATE SCALE 1:11 000 000

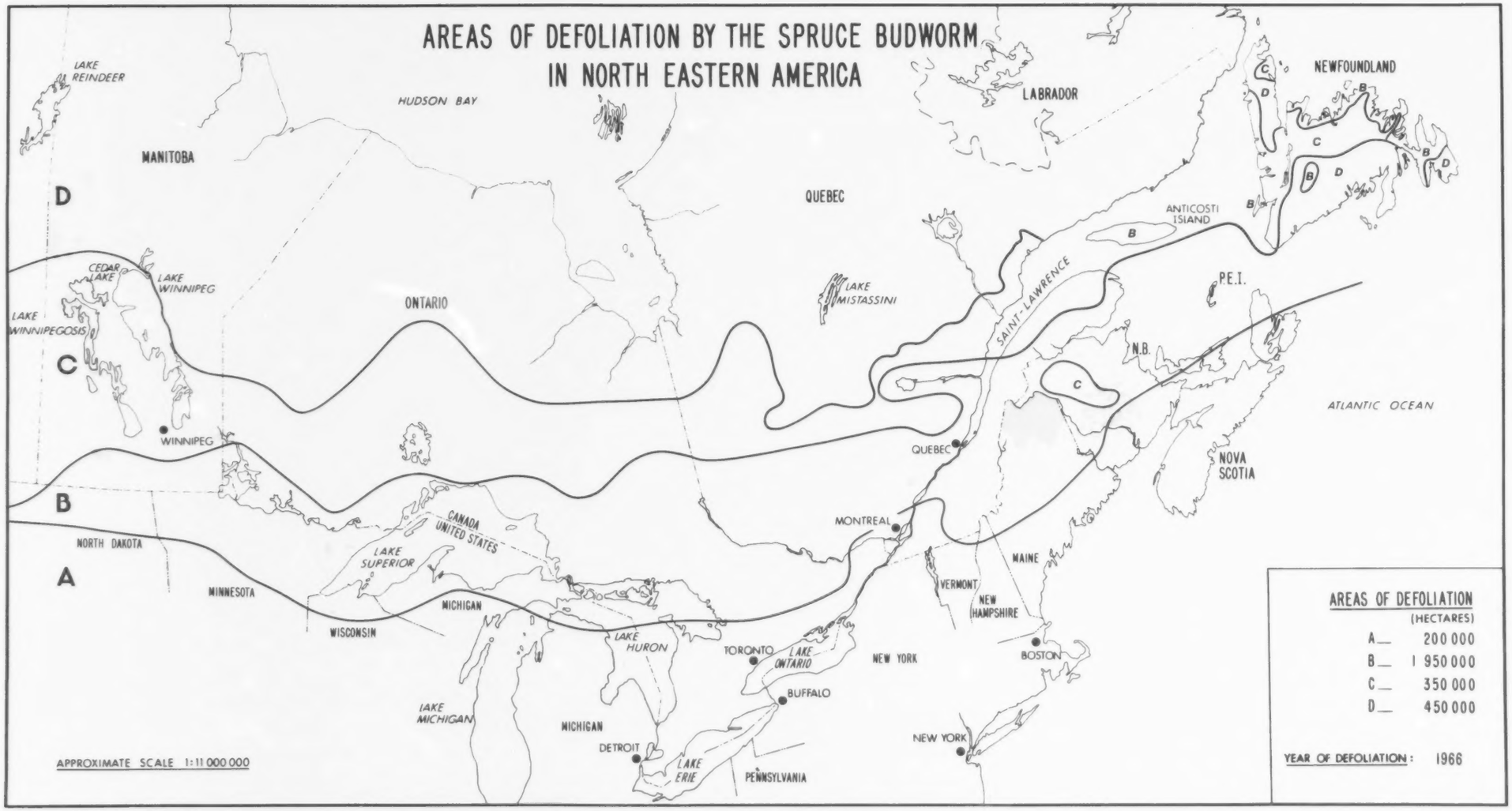
AREAS OF DEFOLIATION

(HECTARES)

A	190 000
B	1 980 000
C	550 000
D	570 000

YEAR OF DEFOLIATION: 1965

AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



APPROXIMATE SCALE 1:11 000 000

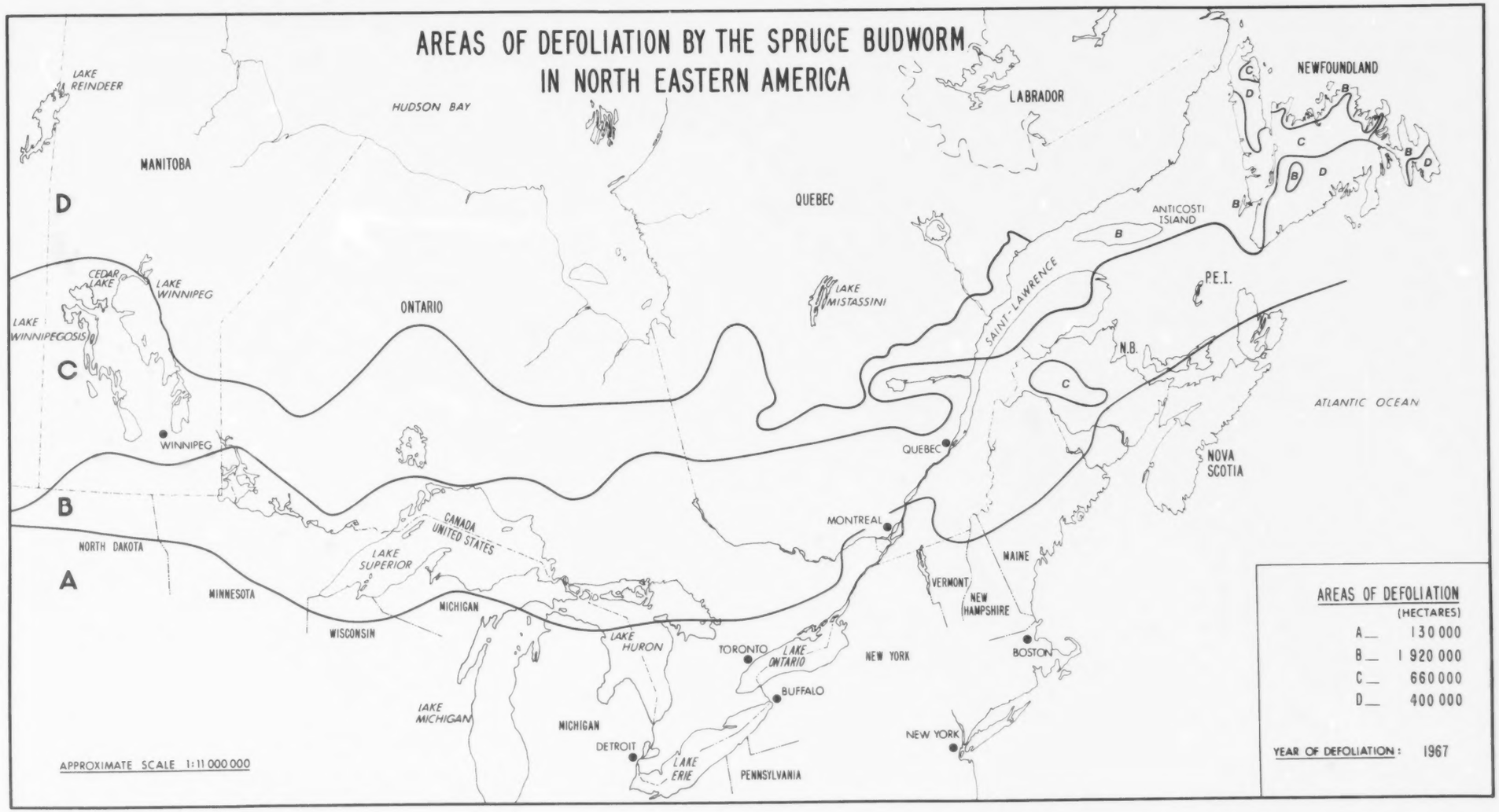
AREAS OF DEFOLIATION

(HECTARES)

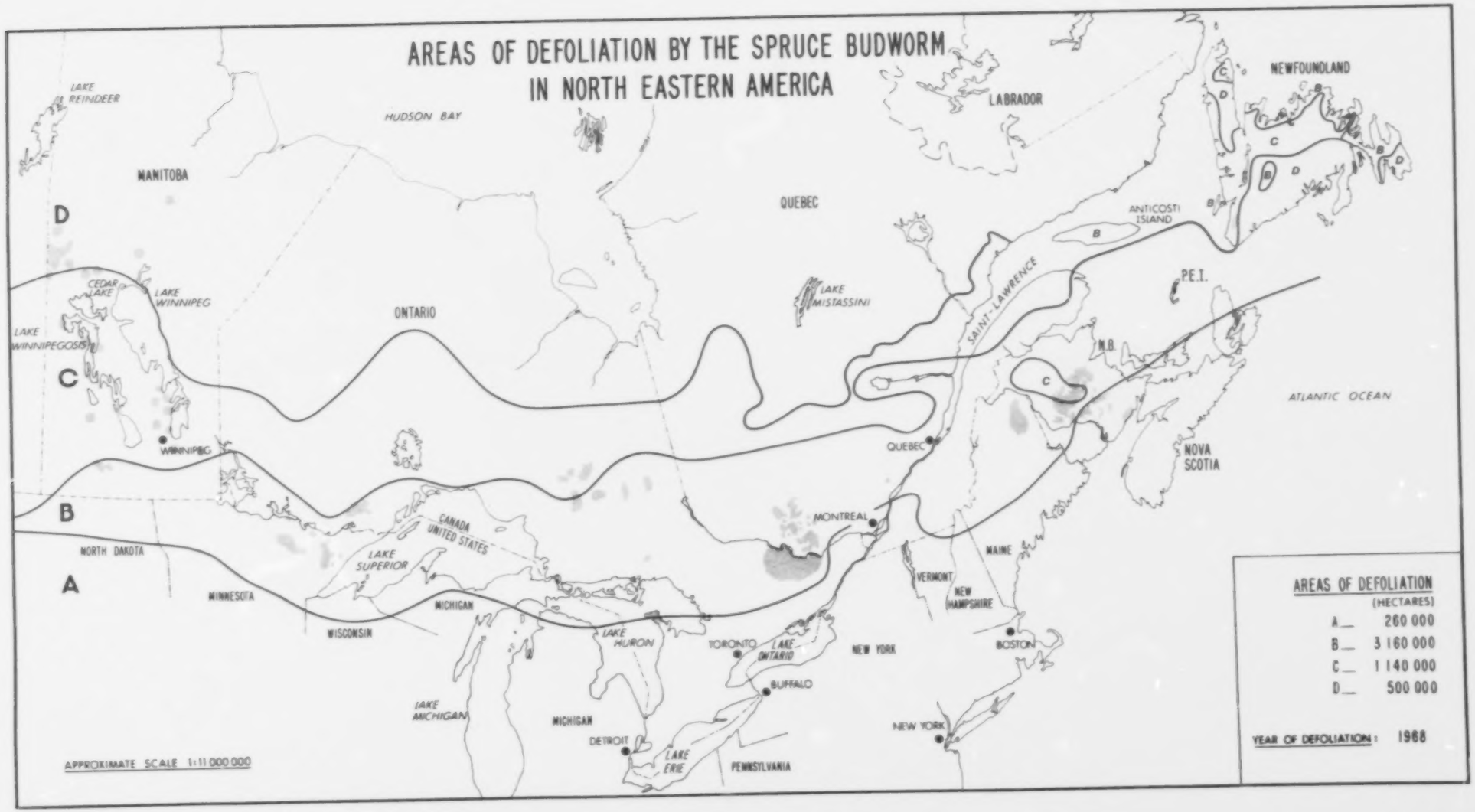
A	200 000
B	1 950 000
C	350 000
D	450 000

YEAR OF DEFOLIATION: 1966

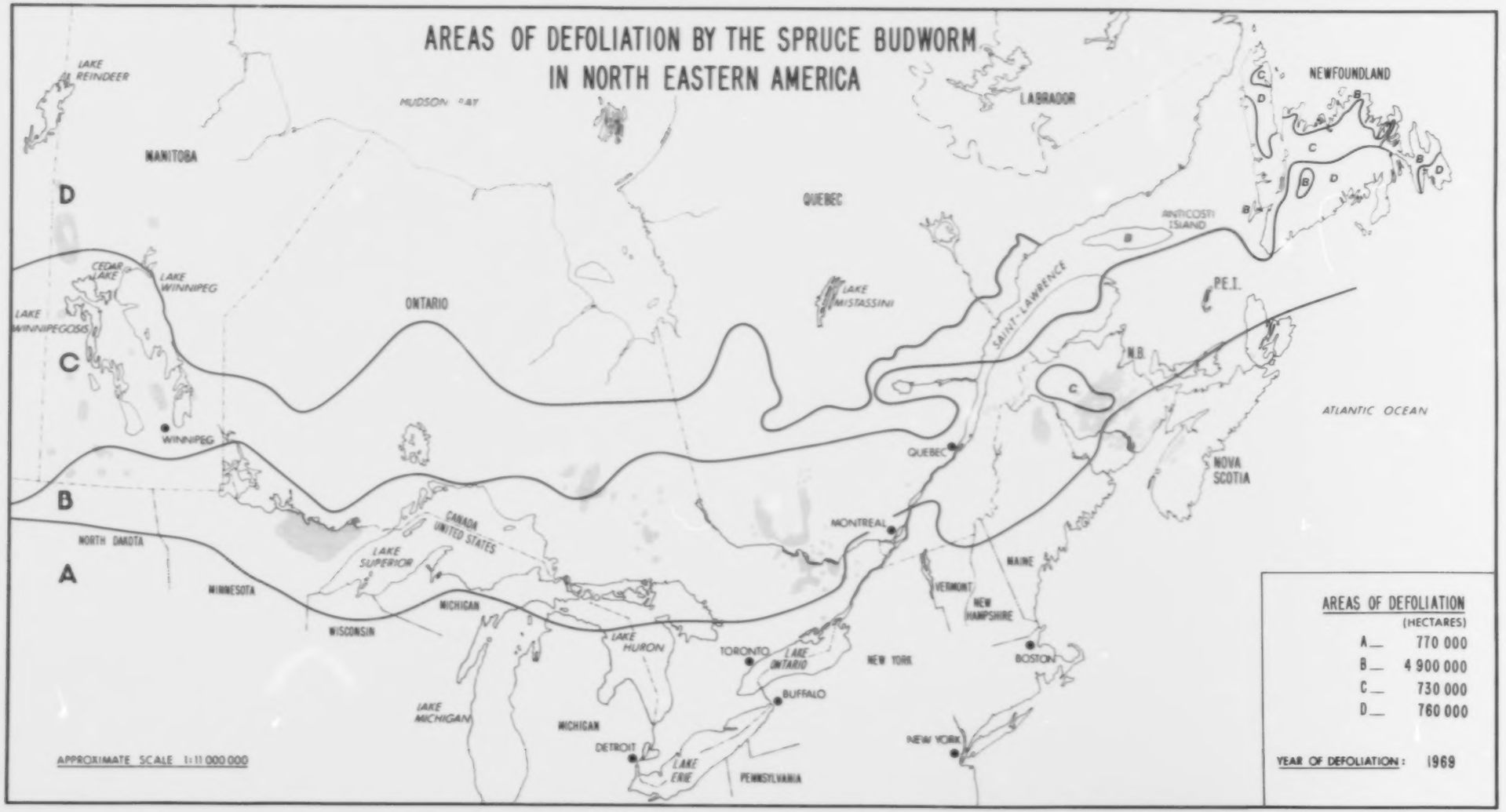
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



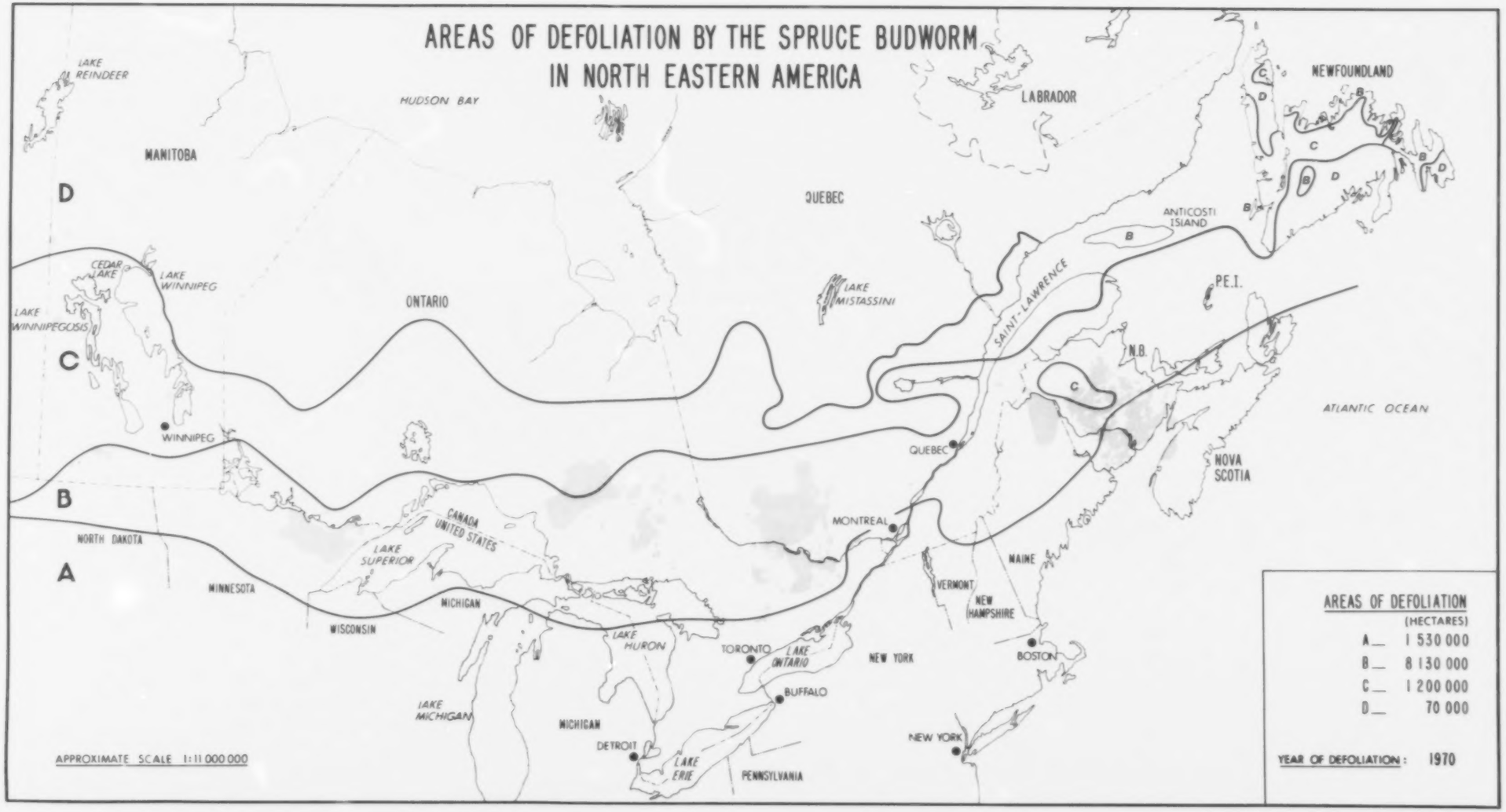
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



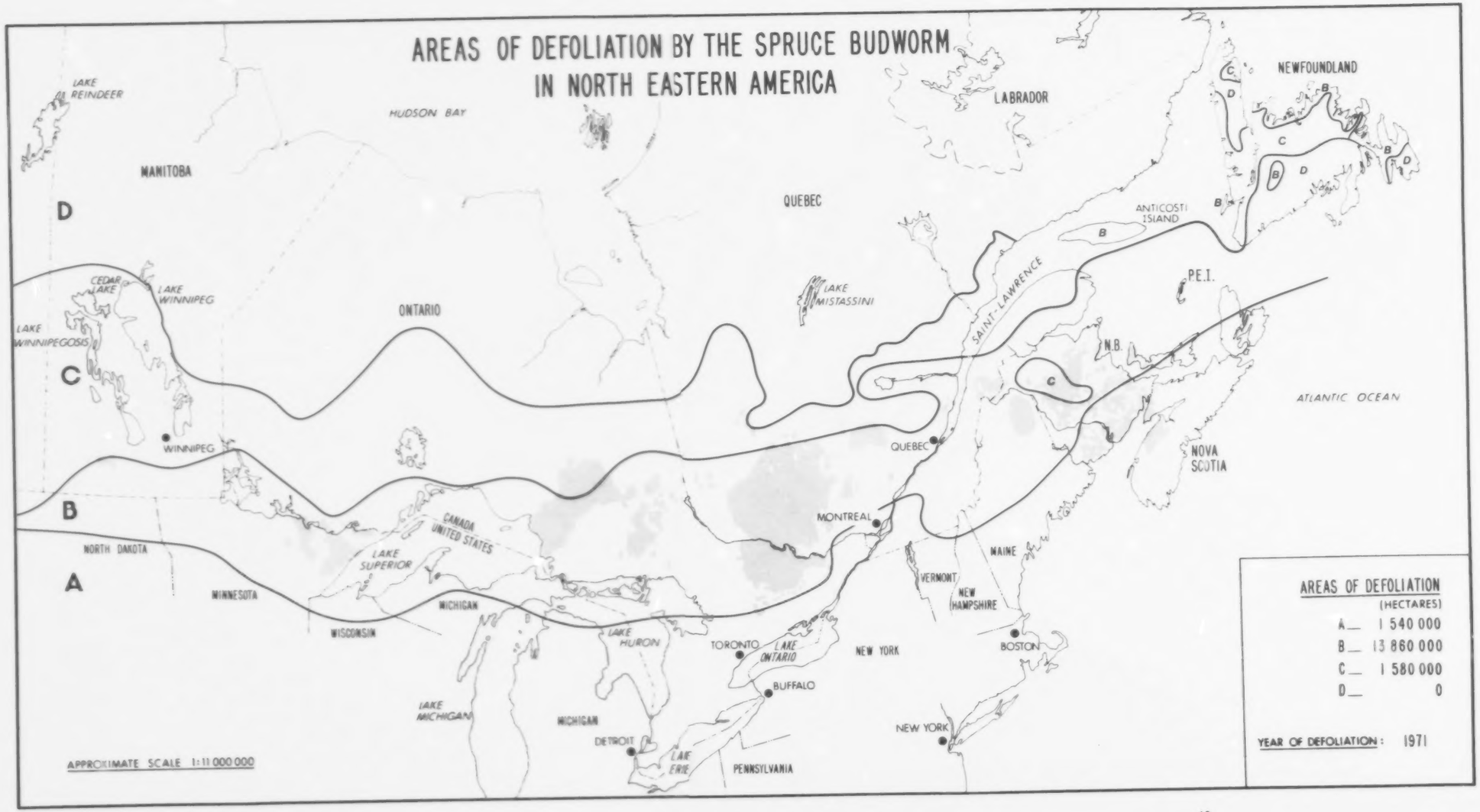
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



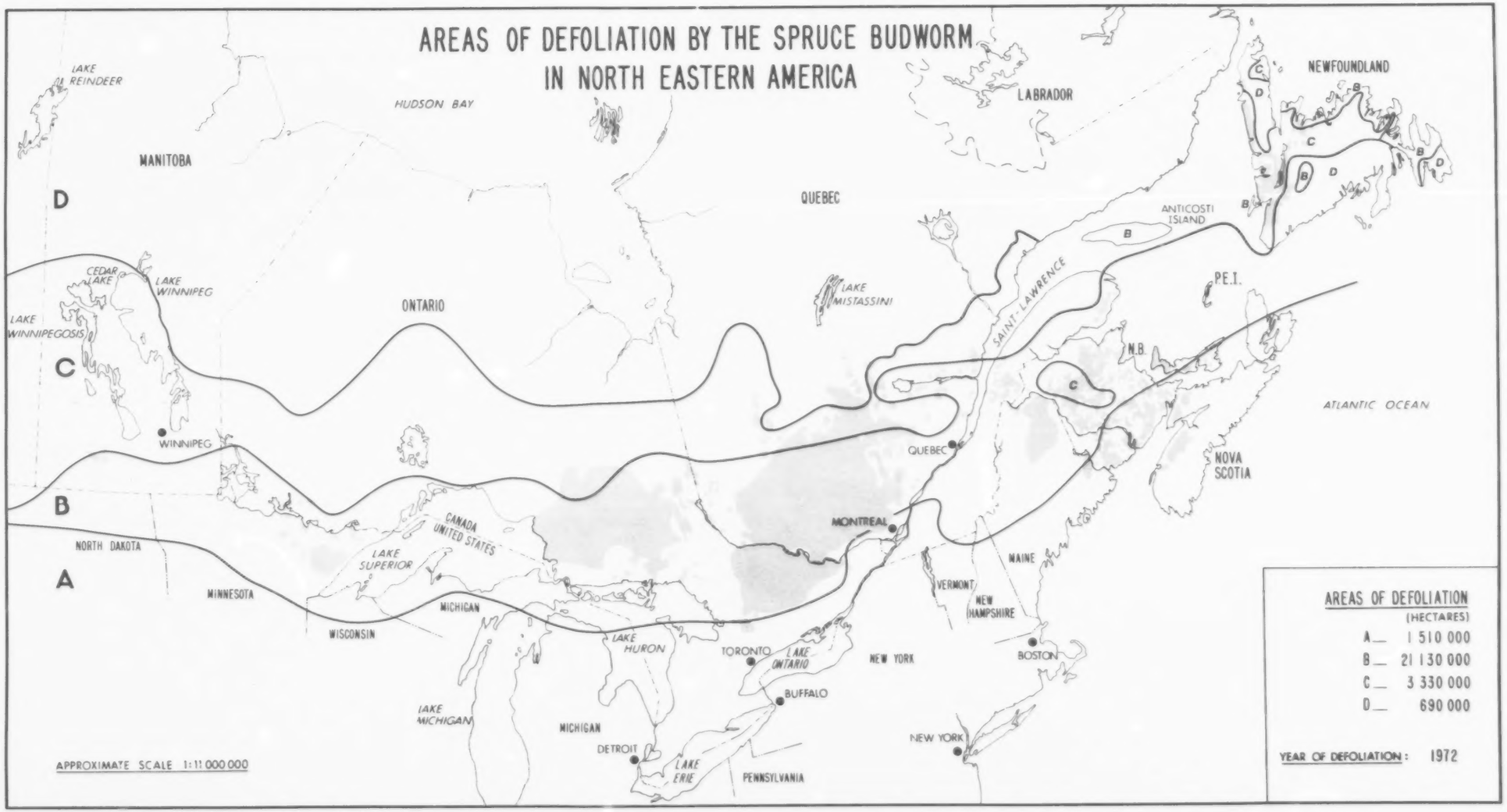
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



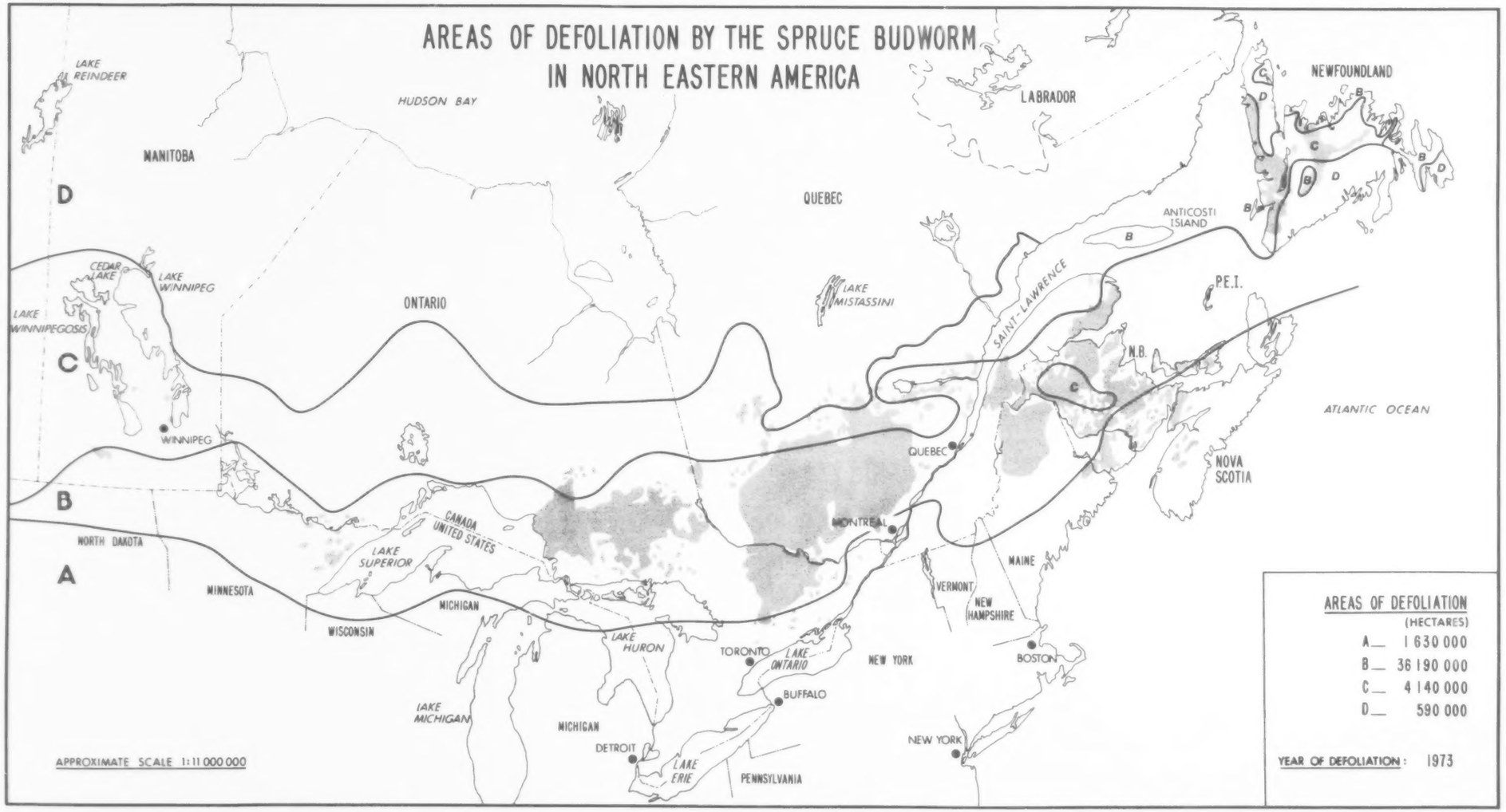
APPROXIMATE SCALE 1:11 000 000

AREAS OF DEFOLIATION
(HECTARES)

A	1 510 000
B	21 130 000
C	3 330 000
D	690 000

YEAR OF DEFOLIATION: 1972

AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



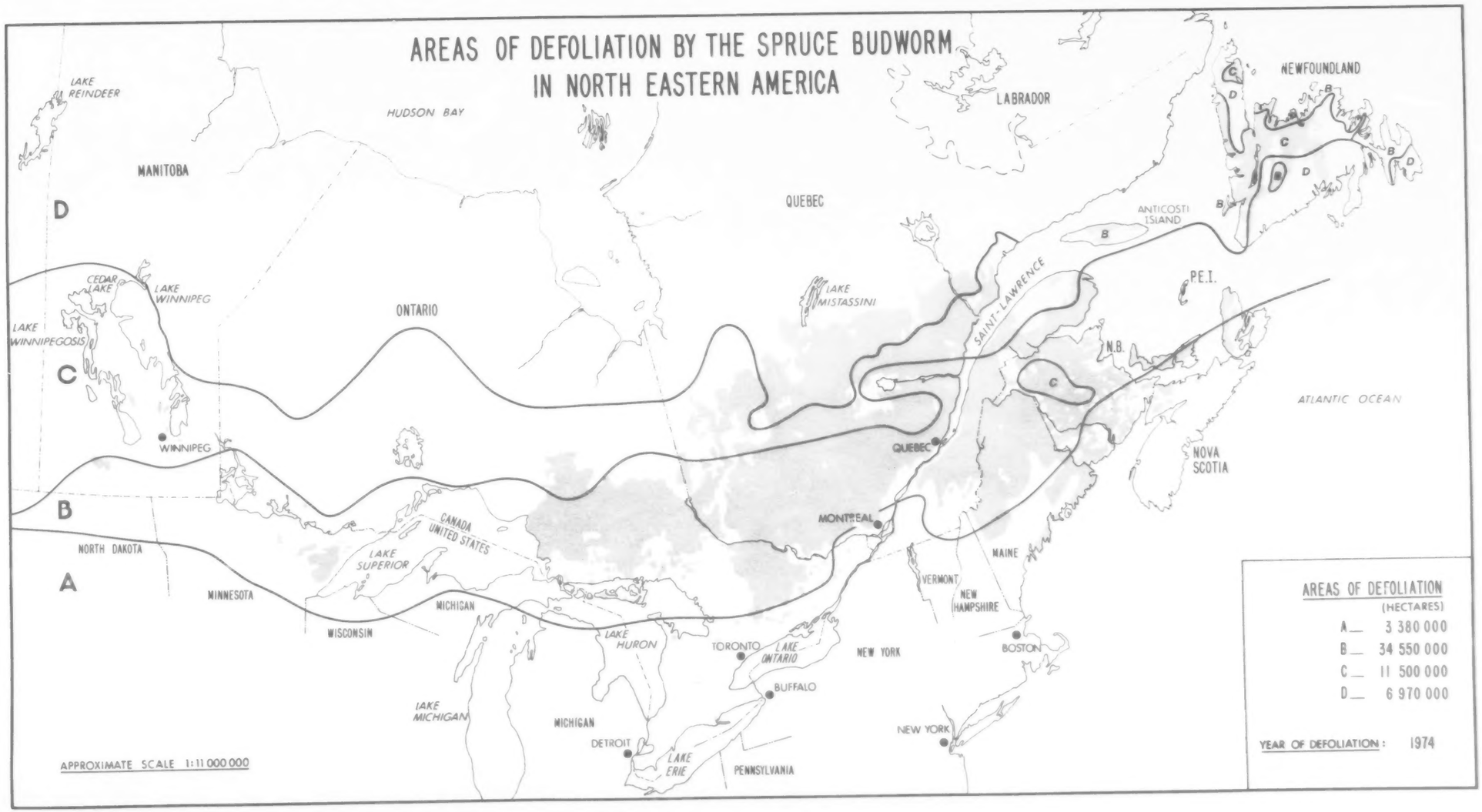
APPROXIMATE SCALE 1:11 000 000

AREAS OF DEFOLIATION
(HECTARES)

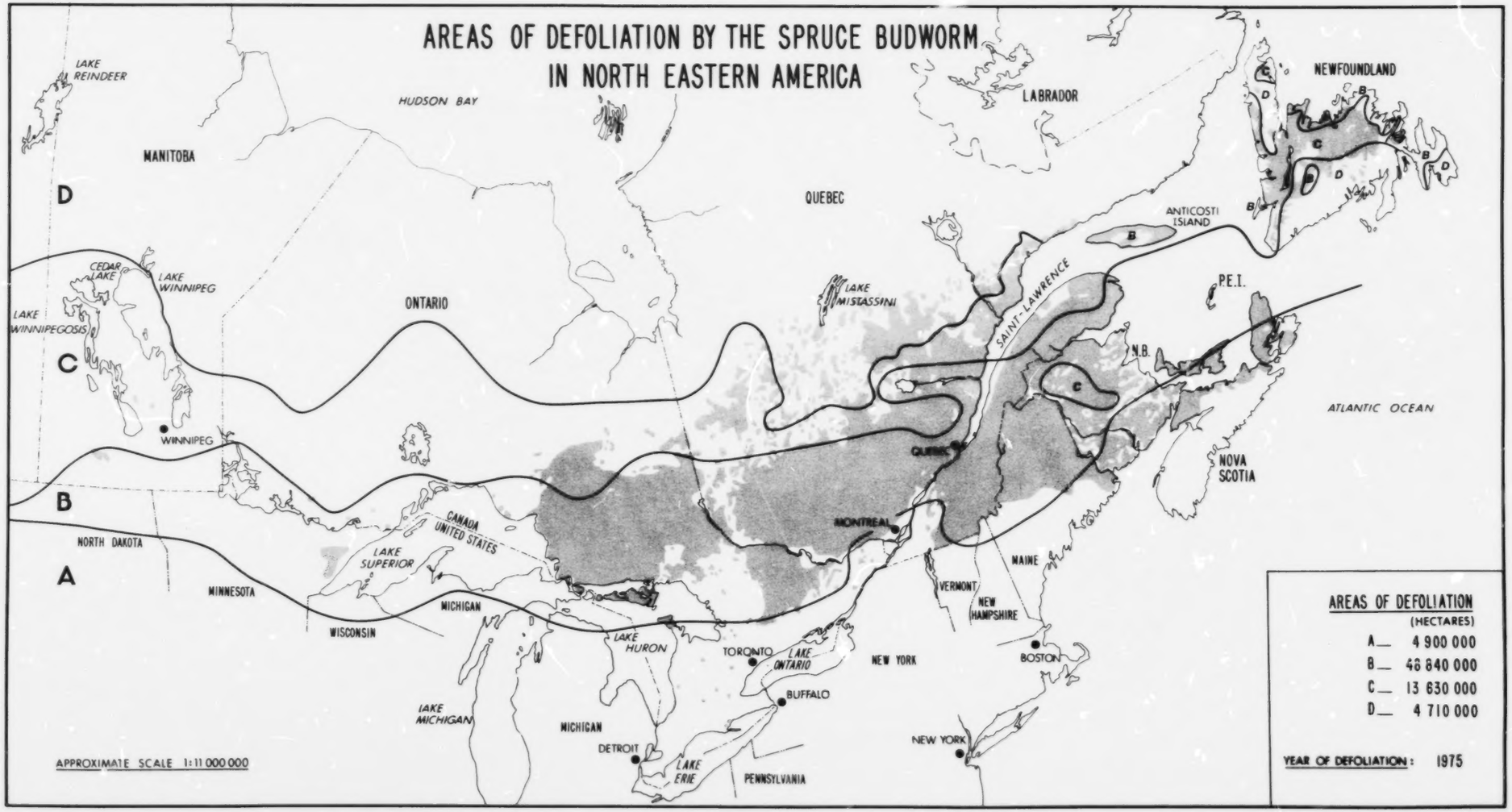
A__	1 630 000
B__	36 190 000
C__	4 140 000
D__	590 000

YEAR OF DEFOLIATION: 1973

AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA

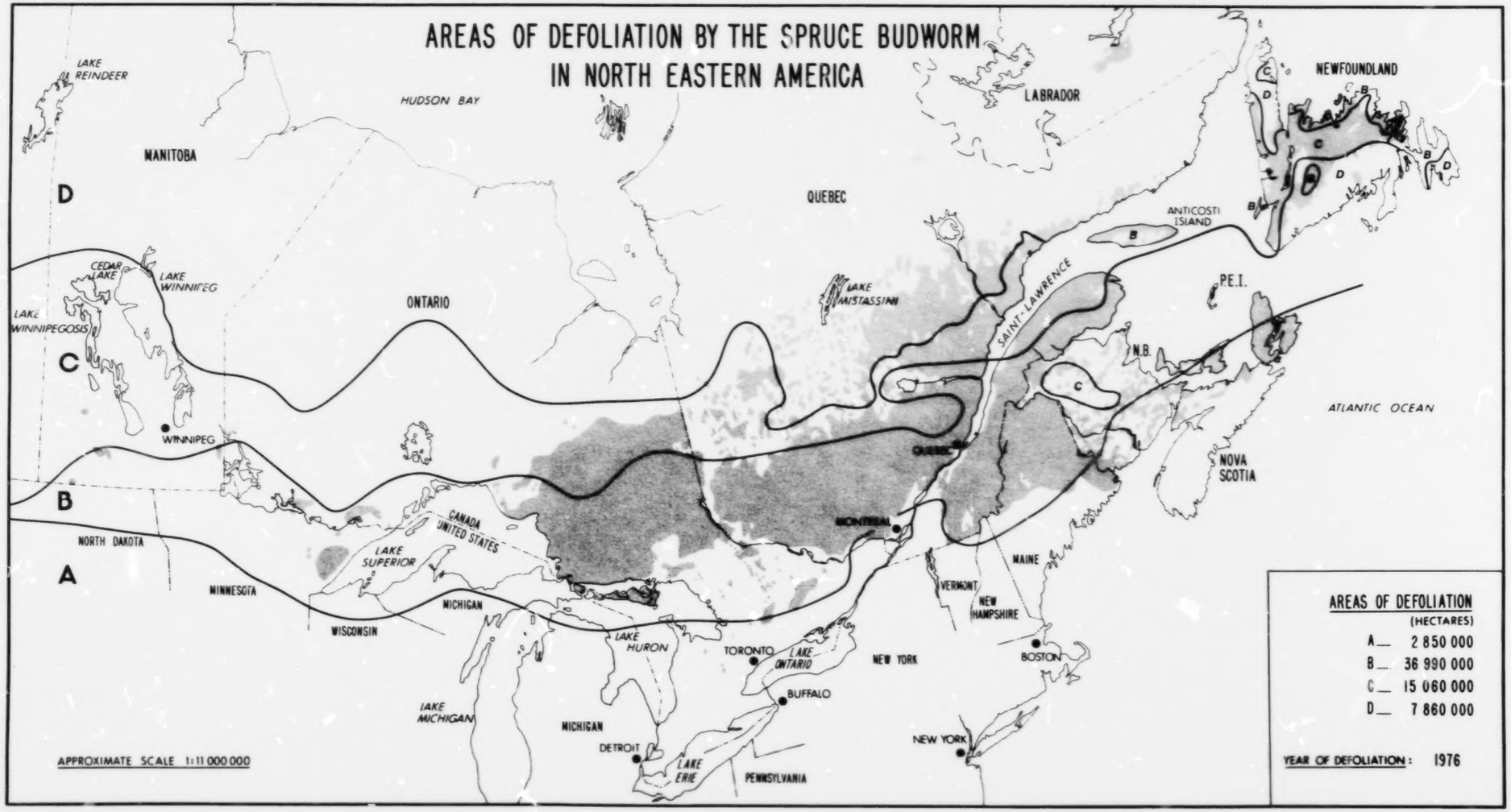


AREAS OF DEFOLIATION
(HECTARES)

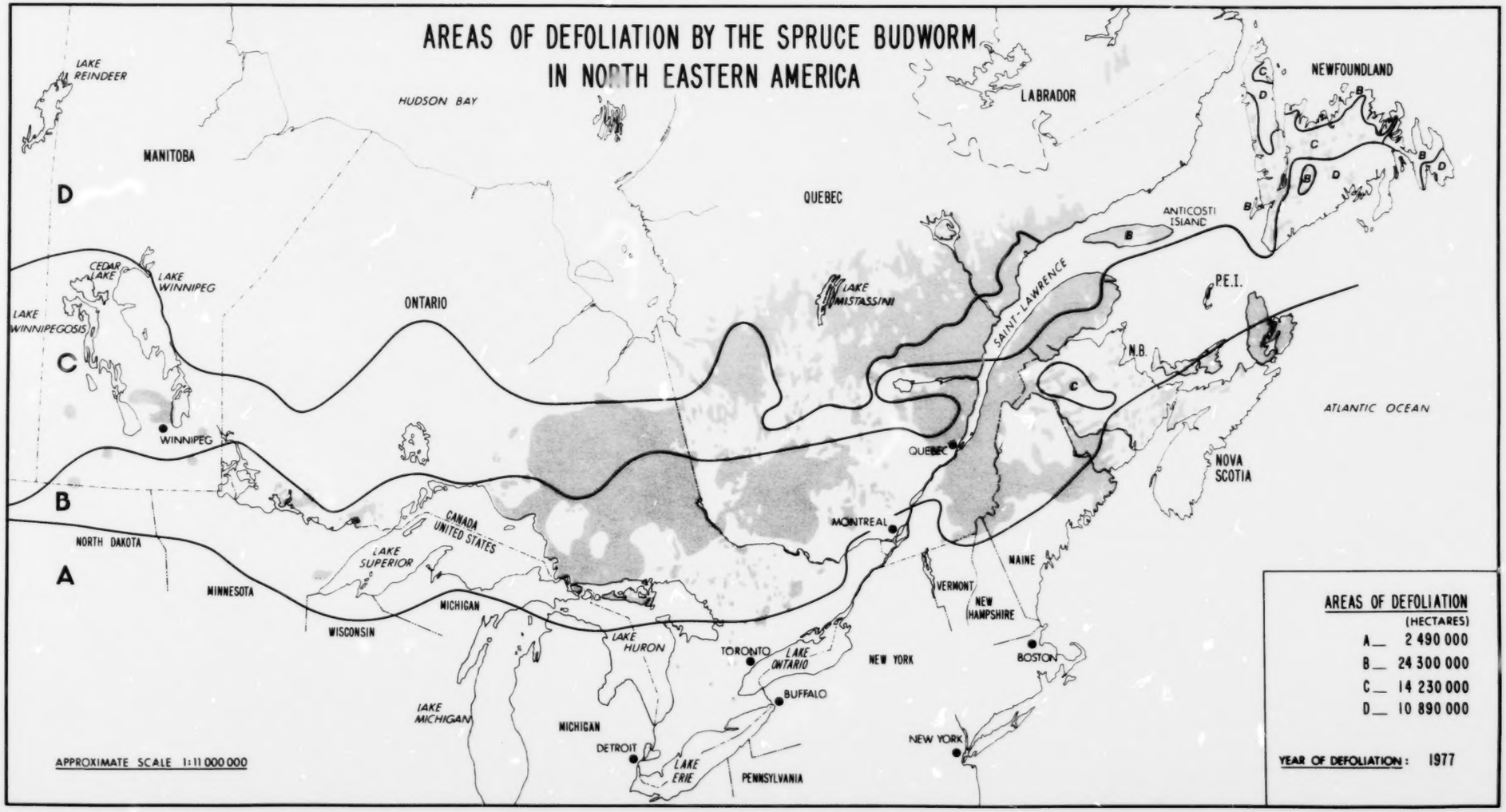
A	4 900 000
B	46 840 000
C	13 630 000
D	4 710 000

YEAR OF DEFOLIATION: 1975

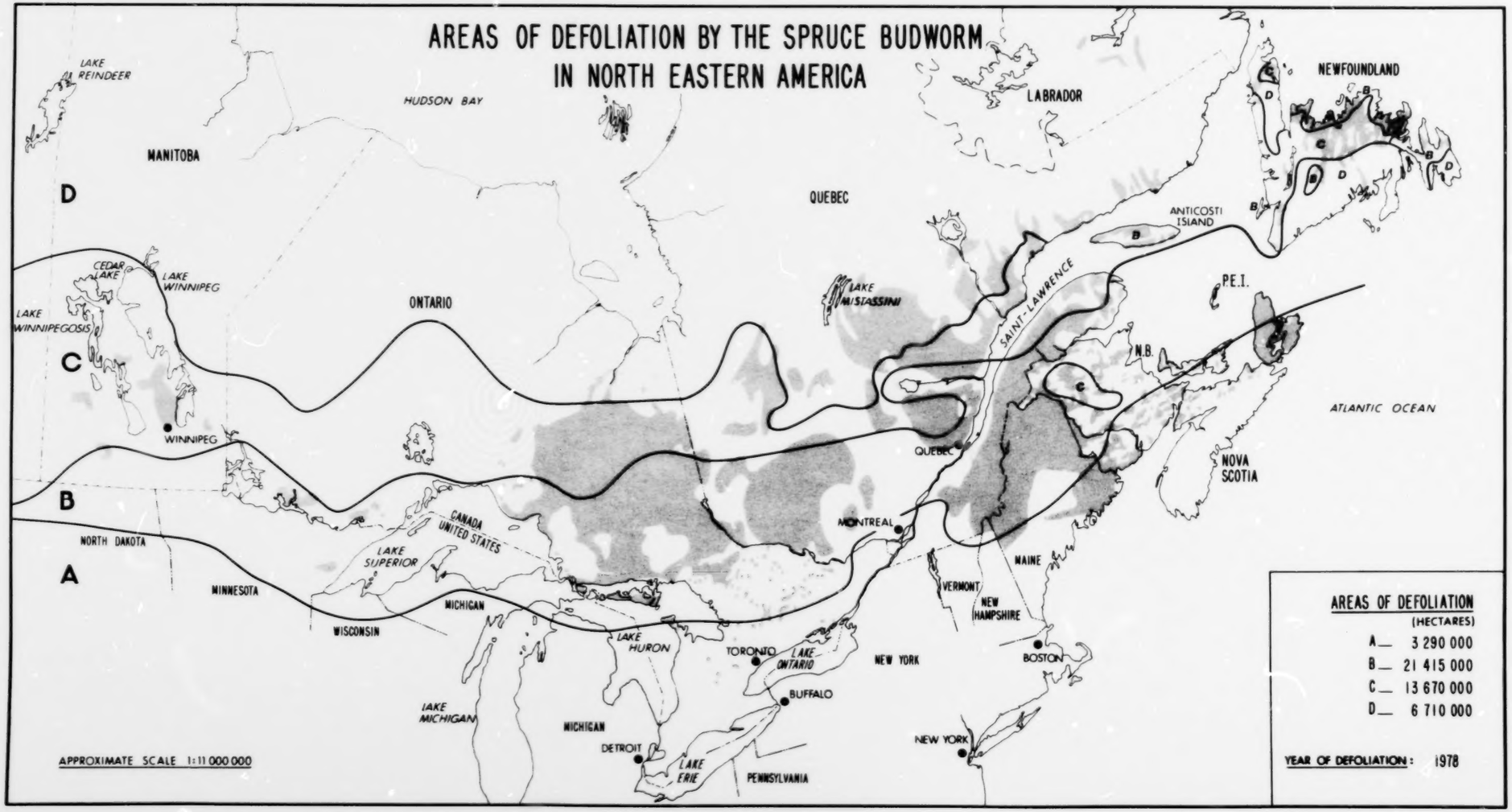
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



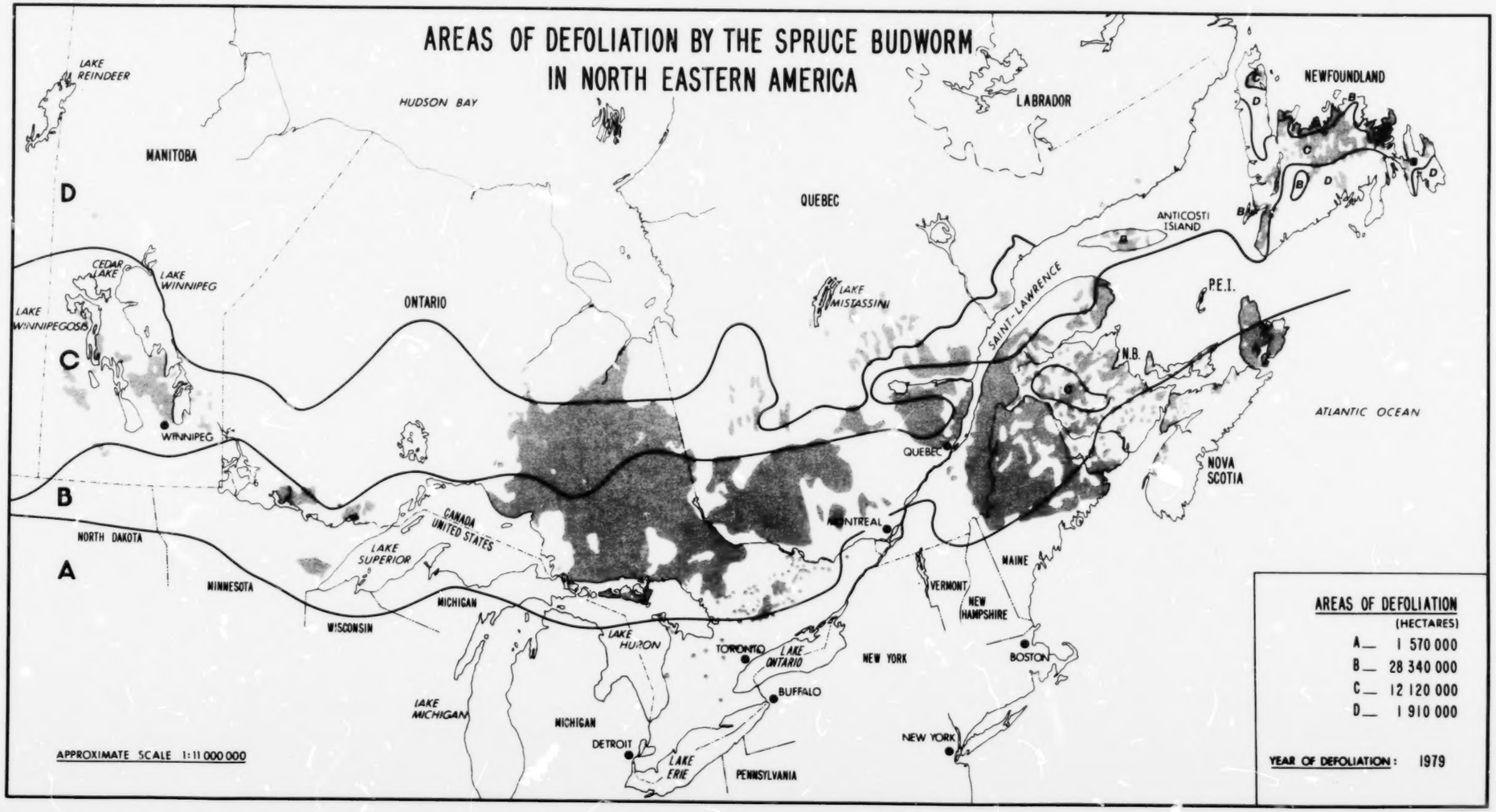
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



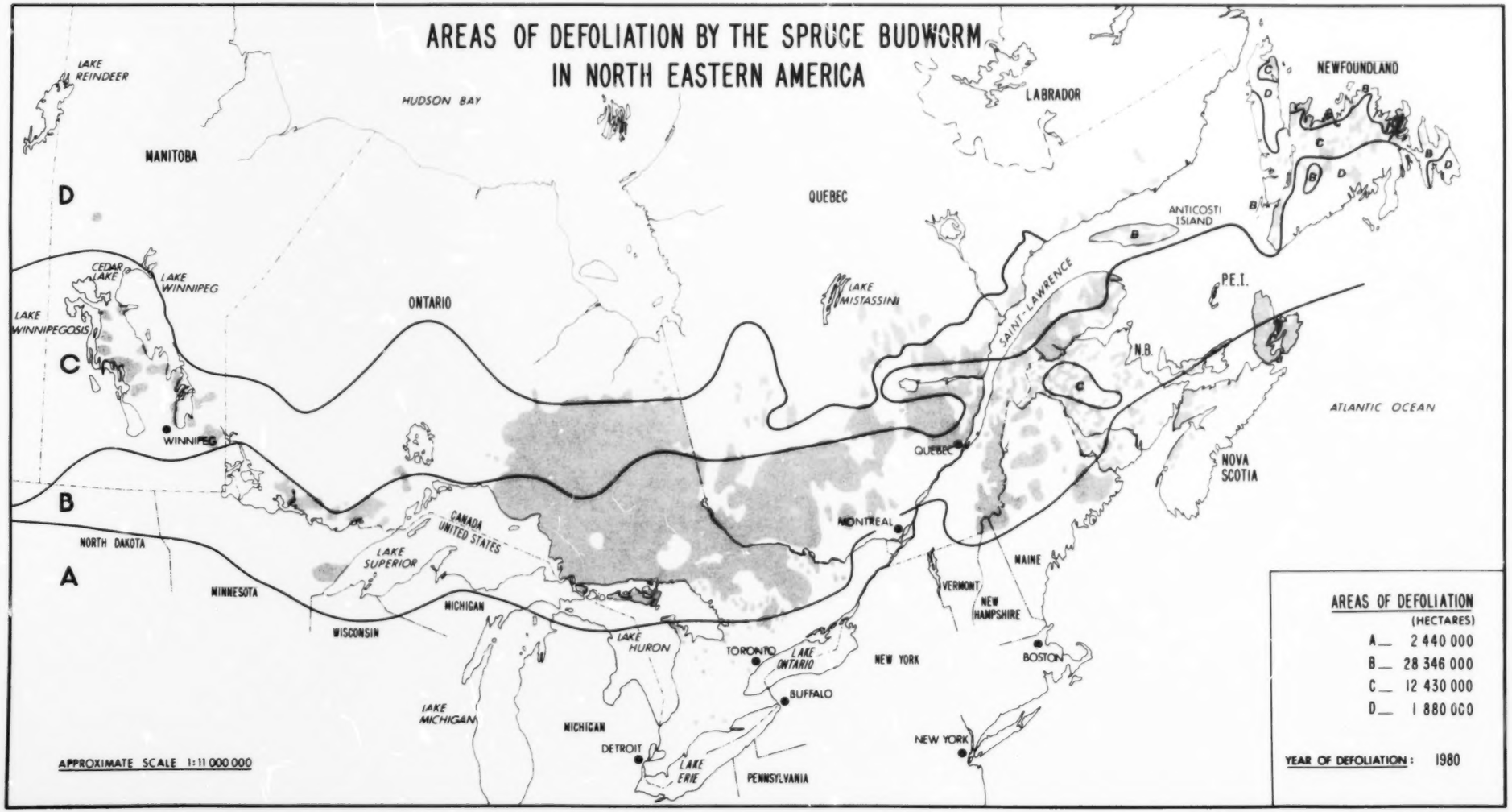
AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



AREAS OF DEFOLIATION BY THE SPRUCE BUDWORM IN NORTH EASTERN AMERICA



canusa

Canada
United States
Spruce Budworms
Program

In 1977, the United States Department of Agriculture and the Canadian Department of the Environment agreed to cooperate in an expanded and accelerated research and development effort, the Canada United States Spruce Budworms Program (CANUSA), aimed at the spruce budworm in the East and the western spruce budworm in the West. The objective of CANUSA was to design and evaluate strategies for controlling the spruce budworms and managing budworm-susceptible forests, to help forest managers attain their objectives in an economically and environmentally acceptable manner. The work represented in this publication was wholly or partially funded by the Program. This manual is one in a series on the spruce budworm.

June 1986